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„Investment in Photovoltaic and Wind Power Plants in Comparison to Coal-Fired Power Plants from the Perspective of a Developing Country“

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Wien, am 28.09.2018

Unterschrift

Foreword

This master's thesis is the crown of my studies at the University of Vienna and the end of a successful life period. I found the inspiration for the research topic back in 2016, when I was chosen to attend the Summer School, an event organized by the Energy Community, an international organization where I currently work as an intern. Back then, in 2016, I made the first contact with the energy sector and immediately developed my interest.

Coming from a developing country like Bosnia and Herzegovina that aspires to join the EU I used my awakened interest for the energy sector to analyze the investment possibilities in so called green energy in my country, mainly from an economic perspective. Perhaps this paper could prove to be useful for the eventual future investors in energy sector of Bosnia and Herzegovina.

I use this opportunity to thank my mentor Dr. Jörg Borrmann for the very helpful suggestions, always quick responses and a high level of professionalism and instructions he provided me in all stages of my master's thesis work.

I would also like to thank my parents Aisa and Mujo Duric, and my brother Nedim Duric for providing me the unconditional support during not only the writing of this paper, but during the whole study period at the University of Vienna. Without their help, my studies would certainly not be possible. I also express my deepest gratitude to the families of Basic, Duric, Hebib and Mahmud who all greatly supported me during my studies in Vienna.

For the end, I thank all the companies, institutions and individuals in Bosnia and Herzegovina that provided me the requested data needed for conducting my research, as well as my dear colleagues at the Energy Community Secretariat.

Servus,

Admir

Abstract (English)

The European Union has positioned itself as a world leader in encouraging the production of electricity from renewable energy sources in order to fight the climate change and global warming. The European developing countries that are yet to join the EU have an obligation to implement energy reforms in accordance with the EU directives. The reality is that the developing countries are unable to track the pace of the EU countries in implementation of renewable energy production with a simultaneous reduction of dependence on conventional coal-fired power plants. At the same time, all the countries that are currently in the EU accession procedures have accepted the obligations of transposing the EU directives, decisions and best European practices into local legislations in the fields of energy, environmental protection, energy consumption and energy efficiency. These obligations have put such countries under massive temptation to seek the best pathway in ensuring the proper ratio between conventional and renewable energy production. On the basis of a case study of the three power plants in Bosnia and Herzegovina, i.e. the first photovoltaic power plant, the first wind farm and the newly planned coal-fired power plant, the paper presents a comprehensive profitability analysis of these investments, with the purpose of comparing the renewables with the conventional energy technologies and finding the optimal production mix from the economic perspective of a developing country. The results of the research indicate that a developing country such as Bosnia and Herzegovina is financially not able to drastically reduce the energy production from conventional sources in favor of renewables. Coal-fired power plants will still play an important role, and a shift towards renewable energy sources will proceed at a relatively slow pace.

Keywords: renewable energy, coal-fired, photovoltaic, wind, LCOE

Abstract (German)

Die Europäische Union hat sich als weltweit führend positioniert in der Förderung der Stromerzeugung aus erneuerbaren Energiequellen, um den Klimawandel und die globale Erwärmung zu bekämpfen. Die europäischen Entwicklungsländer, die der EU beitreten möchten, sind verpflichtet, die Energiereformen im Einklang mit den EU-Richtlinien durchzuführen. Die Realität ist, dass die Entwicklungsländer nicht in der Lage sind, das Tempo der EU-Länder bei der Umsetzung der Stromerzeugung aus erneuerbaren Energien zu verfolgen und gleichzeitig die Abhängigkeit von konventionellen Kohlekraftwerken zu verringern. Gleichzeitig haben alle Länder, die sich derzeit in den EU-Beitrittsverfahren befinden, die Verpflichtung zur Umsetzung der EU-Richtlinien, Entscheidungen und besten europäischen Praktiken in lokale Gesetzgebungen in den Bereichen Energie, Umweltschutz, Energieverbrauch und Energieeffizienz übernommen. Diese Verpflichtungen haben solche Länder stark in Versuchung geführt, den optimalen Weg zu finden, um das richtige Verhältnis zwischen konventioneller und erneuerbarer Energieproduktion zu gewährleisten. Auf der Grundlage der Fallstudie dreier Kraftwerke in Bosnien und Herzegowina, d.h. dem ersten Photovoltaik-Kraftwerk, dem ersten Windpark und einem neuem geplanten Kohlekraftwerk, wird eine umfassende Rentabilitätsanalyse dieser Investitionen vorgestellt, um die erneuerbaren Energien mit den konventionellen Energietechnologien zu vergleichen und aus der wirtschaftlichen Perspektive eines Entwicklungslandes den optimalen Produktionsmix zu finden. Die Ergebnisse der Forschung zeigen, dass ein Entwicklungsland wie Bosnien und Herzegowina finanziell nicht in der Lage ist, die Energieerzeugung aus konventionellen Quellen zugunsten der erneuerbaren Energien drastisch zu reduzieren. Kohlekraftwerke werden weiterhin eine wichtige Rolle spielen und die Umstellung auf erneuerbare Energien wird relativ langsam vorgehen.

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List of Abbreviations

AC…………..... Alternating Current
BAM…………..Bosnian Mark
BAT…………...Best Available Techniques
BC……………. Buyer's Credit
BiH…………… Bosnia and Herzegovina
CAPEX………. Capital Expenditure
CapF………….. Capacity Factor
CCGT…………Combined Cycle Gas Turbine
CoE……………Cost of Electricity
DC……………. Direct Current
EU28…………. The 28 member states of the EU
Eurostat………. Statistical Office of the European Communities
FBiH…………..Federation of Bosnia and Herzegovina
GDP…………...Gross Domestic Product
GHG………….. Greenhouse Gas
IRR…………… Internal Rate of Return
LCOE………… Levelized Cost of Energy
m a.s.l………… Meters Above Sea Level
NPV………….. Net Present Value
NREAP BiH…..National Renewable Energy Action Plan of Bosnia and Herzegovina
O&M…………. Operation and Maintenance
OCGT…………Open Cycle Gas Turbine
PBC…………... Preferential Buyer's Credit
PV……………..Photovoltaic
PVGIS………... Photovoltaic Geographical Information System
RS……………..Republic of Srpska
WB6………….. West Balkan Six
WF…………….Wind Farm

List of Symbols

CO_2…………....Carbon dioxide

€ct……………..Euro cent

GJ…………….. Gigajoule

GWh………….. Gigawatt hour

kJ……………... Kilojoule

ktoe…………....Kiloton of oil equivalent

kV……………..Kilovolt

kW…………….Kilowatt

kWh…………...Kilowatt hour

kWp…………...Kilowatt peak

mg……………..Milligram

MW…………... Megawatt

MWh…………. Megawatt hour

MWp…………. Megawatt peak

Nm^3…………... Standard cubic meter

NO_x……………Nitrogen oxide

SO_2…………… Sulfur dioxide

tCO_2…………...Ton of carbon dioxide

Tg…………….. Million tons

TWh………….. Terawatt hour

Wp…………….Watt peak

1. Introduction

The increase in consumption of fossil fuels in the world with a simultaneous reduction of their non-renewable exploitation reserves marked the end of the 20th and the start of the 21st century. This growing demand for energy has been generally accompanied by a steady upward trend in prices of fossil fuels, with occasional smaller or larger deviations.

Negative consequences of the use of fossil fuels in the energy production, most notably the increasingly significant climate change, have prompted humanity to rapidly think about using new innovative energy sources, applying energy efficiency technology and managing energy consumption more rationally.

Today, it is globally accepted that the principles of sustainable economic development, economic growth and competitiveness, as well as environmental protection, are impossible without the use of innovative solutions in energy production from renewable sources and without the implementation of energy efficiency technologies in consumption.

Developing countries, such as Bosnia and Herzegovina (from this point onwards referred to as BiH), are in a much more difficult situation than the developed countries of the European Union (EU) in terms of the ability to apply innovative solutions and technologies for the production of energy from renewable energy sources. First of all, the reason can be found in an economic underdevelopment expressed through a significantly smaller GDP compared to the developed EU member states. If we add to this the multiple internal weaknesses and peculiarities that negatively affect the ability to attract foreign capital and investments, the investment opportunities in renewable energy are significantly narrowed. A general opinion is that BiH, as well as the other developing countries, in the foreseeable future cannot meet the conditions for a full transition to the production of electricity from renewable sources while simultaneously shutting down the coal-fired power plants. However, by choosing the best production mix between the electricity produced from renewable sources on the one side and from coal-fired power plants on the other, such countries can ensure sustainable economic development, a positive rate of economic growth and competitiveness, as well as the environmental protection in line with the commitments undertaken on the road to EU accession.

This paper was devoted to solving these issues and finding the optimal mix between electricity production coming from conventional and renewable energy sources, and consists of eight main chapters.

Chapter 1 will introduce the subject, objectives and purpose of research, evaluation of existing research, methodology of research and set the expected outcomes and results.

Chapter 2 presents the EU legal framework for energy and climate change and the legal framework of the Energy Community.

Chapter 3 provides a brief statistical and historical overview of the trends of electricity production in the EU for both conventional power plants and power plants based on renewable energy as well as their comparison with an emphasis on changes in the production structure in favor of renewable energy sources. In addition, this chapter will break down the cost structure of electricity production from different technologies and present the historical Levelized Cost of Energy (LCOE) data for conventional and power plants based on renewable energy.

Chapter 4 provides a description of the software tools used for the later calculations, as well as the description of the theoretical basis and the mathematical formulation of all the in the later chapters used tools for determining the profitability of electricity production from conventional and renewable energy sources.

Chapter 5 is the case study of the 3 power plants in BiH: photovoltaic power plant "Kalesija" (from this point onwards referred to as PV power plant "Kalesija"), wind farm "Mesihovina" (from this point onwards referred to as WF "Mesihovina") and coal-fired power plant "Block 7 Tuzla" (from this point onwards referred to as simply "Block 7 Tuzla). Each of the three power plants is analyzed in detail with the conducted feasibility study of electricity production from these power plants and the profitability assessment of these investments.

Chapter 6 analyzes how the three power plants that were subject of the case study in the previous chapter, react to changes in the key sensitive factors that have a decisive influence on the feasibility of electricity production in these power plants. In addition, the external factors are taken into account as well.

Chapter 7 includes final comparison of the three power plants and concluding considerations on the feasibility of electricity production from renewable sources of solar and wind energy compared to the production from coal-fired thermal power plants in BiH. This chapter provides recommendations on which path in the energy sector, BiH and similar developing countries should undertake.

The final, Chapter 8 eight summarizes the results of the whole research and provides a conclusion.

As already mentioned earlier, Chapter 1 is divided into 5 sections. Section 1.1 will present the subject of the research, Section 1.2 the research objectives and purpose, Section 1.3 evaluation of existing research, while sections 1.4 and 1.5 will explain the research methodology and set the expected outcomes of the research respectively.

1.1 Research Subject

The final and ultimate subject of the research was the question of choosing the best technology for electricity production in BiH as an example of a developing country, i.e. electricity production from renewable sources, from conventional power plants or a mix of both. In order to find the answer, many aspects needed to be analyzed. Some of these were: the impact of electricity production by different technologies on global climate change and the local environment, the issues of Carbon Dioxide (CO_2) emission costs and emission trading, as well as the role and importance of the availability of electricity at economically acceptable and stable prices, in the function of preserving economic competitiveness.

Furthermore, with regards to costs and electricity pricing, especially influential on the profitability of the investment in one over the other electricity production technology are: initial investment costs; operation and maintenance (O&M) costs; ways and sources of funding of the construction of power plants; the return on investment within the lifetime of the power plant; availability and prices of energy sources (coal, wind and sun energy);

policies of redemption prices, incentives and subsidies in the production of electricity from renewable sources; as well as the issues and impact of regulatory restrictions on the formation of the price of produced electricity.

The EU itself plays an important role when it comes to the energy sector in developing countries that aspire to become full members of the European Union. The EU is the world’s leader in the application of the technologies based on renewable sources for the production of electricity and as such has a significant impact on the choice of the optimal type of power plant to invest in. In this relation several aspects were analyzed, such as: the impact of the EU policies on the reduction of greenhouse gas (GHG) emissions, the increase of production share from renewable energy sources and implementation of energy efficiency measures; as well as the impact of the creation of a single internal electricity market of the EU countries and the contracting parties of the Energy Community.

Certainly, all the above mentioned factors influence the investment decision when it comes to choosing between coal-fired power plants and power plants based on renewable energy, in this paper mainly those that use solar and wind energy. These factors, i.e. their impact on the final profitability of these power plants, were the subject of this research. From a strictly economic point of view, this analysis should prove to be sufficient for the investment decision. Speaking about non-economic related areas, certainly in addition, there are some other factors of different kind that can also heavily influence the investment decision, or even fully stop it, such as e.g. the impact of public and political attitudes of the authorities and local communities on making decisions on investing in the construction of new power plants. However, because of their complexity, such factors were not researched and analyzed in detail in this paper.

1.2 Research Objectives and Purpose

Electricity production in BiH has traditionally been dependent on the production coming from conventional coal-fired power plants. However, the undertaken obligations of promoting, producing and stimulating the production of electricity from renewable energy sources have imposed the need for the adoption of national action plans for the use of renewable energy sources. This challenge has been put in front of each of the Western Balkans countries.

At the same time, the issue of determining the level of investments in renewable energy was imposed, i.e. the determination of the investment return limits that will balance the obligations from the national action plan for the use of renewable energy sources on the one hand and the investment possibilities on the other.

The aim of the research was to analyze the current status and opportunities in the field of electricity production from conventional power plants and power plants based on renewable energy sources in BiH, as well as prospects and directions of further development of electricity production, taking into account most of the relevant factors influencing the investment choice regarding both of these technologies.

The purpose of the research was to confirm that BiH, by simultaneously investing in the restructuring of mines and coal-fired power plants on one hand and production from renewable sources to the quota defined in the national action plan on the other, can ensure energy independence, sustainable economic development, economic growth and competitiveness, and environmental protection. In other words, a mix between the two technologies is currently the only profitable way to produce electricity in BiH and other countries of similar development status.

1.3 Evaluation of Existing Research

A considerable number of statistical reports and scientific and expert papers have been published, regarding the issue of energy production and gradual replacement of energy production from fossil fuels with renewable energy sources.

However, it is still unclear whether the renewable energy production will be able to completely replace the production of energy from fossil fuels and when will this happen. This issue is particularly a hot topic when it comes to developing countries, since they are regularly over-dependent on the electricity production from conventional power plants.

When it comes to profitability of the individual types of power plants, some research papers have shown that even a slight variation of some of the specific factors within a single technology (be it conventional or renewable energy plants) can be a significant source of risk for making a decision to invest in certain type of energy production. These factors and their impact might not have been explored sufficiently in existing papers and reports.

Furthermore, many reports focus on the goals set by the EU in terms of directives and regulations in the field of energy sectors that the developing countries should by all means implement if their accession to the EU is going to be successful. However, besides the clearly stated goals, often in terms of shares of each type of technology in the final electricity production mix, very few reports actually focus on the question of how the particular EU candidate country is going to achieve these goals, and whether it has capabilities to fulfill the set requirements. Problems such as the inability to attract foreign investors or the number of employees in coal mines and coal-fired power plants that would lose their jobs in case of a full transition to the electricity production from renewable sources, are often overlooked. This paper tries to overcome these deficiencies by providing the strategy that the developing countries such as BiH could follow in the future.

1.4 Research Methodology

Taking into account the nature of the researched subject, the only reasonable path on answering the main research question in a trustworthy and fact-based way, was to conduct and design the work in the form of empirical quantitative research. The thesis is centered on the personally conducted case study of the three power plants in BiH.

The research has the following structure, ordered and conducted chronologically:

- introduction of the topic - the subject, purpose, objectives and evaluation of existing research, as well as description of the used scientific methods and the structure of the research;
- setting the theoretical background on the legal framework for energy and climate change in the EU, the Energy Community and BiH;
- the historical, theoretical, retrospective and explicative part showing the trends in production and electricity costs in the EU, the Energy Community and BiH;
- the explanation and theoretical basis, as well as the presentation of the calculation methods and mathematical formulation of the tools used for the later profitability analyses;

- case study of the three power plants in BiH: photovoltaic (PV) power plant "Kalesija", wind farm (WF) "Mesihovina" and coal-fired power plant "Blok 7 Tuzla"; this is the analytical-experimental part of the work with two stages:
    - collection (and in case of PV power plant additional simulation of data using Photovoltaic Geographical Information System - PVGIS software) and display of the relevant financial data for the above mentioned power plants;
    - analysis of the collected (and simulated) data and the calculation of profitability on an individual basis for each of the three power plants, based on the methods, mathematical formulations and software tools explained in the preceding chapter;
- the analytical-experimental part in which the (in the preceding chapter calculated) profitability indicators are subject to experiments in form of changes in the key parameters that influence the profitability of electricity production in the three analyzed power plants; in addition, this part of the work takes into consideration the external factors of all three power plants as well;
- the final part in which the calculated profitability indicators are compared between all three power plants as representatives of three different technologies and final considerations and recommendations on the mix in electricity production that BiH and similar developing countries should follow; this part will provide answers on whether BiH and similar countries should follow the policies of gradual reduction of the number of coal-fired power plants on their ultimate path of eventually being one day completely substituted by the production from renewable sources.
- the conclusion, which summarizes the results of the research and once again displays the achieved results and recommendations regarding the future path of the developing countries and BiH, in terms of the energy sector.

During the whole research and analysis process, the following data sources, permissions and specialized software were the most important ones used in order to help conduct the research or to automate some calculations:

- EU and Energy Community legal framework for energy and climate change, i.e. Energy Community acquis communitaire;

- real financial raw data acquired personally, i.e. financial and technical data of the PV power plant „Kalesija“, WF „Mesihovina“ and „Blok 7 Tuzla“;
- PVGIS Software – a specialized software for simulation of energy production in PV power plants;
- FRACTAL Split Software – a specialized software for financial analyses and automation of the financial-related calculations.

1.5 Expected Results

The results of the research, based on the analysis of the key economic and financial indicators, should be viewed as a roadmap or guideline in which direction and scope it is rational and economically profitable to invest in the restructuring of existing production from conventional power plants on the one side and production from renewable energy on the other, in the medium term until 2030, or for long-term projection until 2050 in BiH.

Prior to the start of this research, the following three scenarios were assumed as the possible conclusions based on the research results:

a) rehabilitation of the existing coal-fired power plants by installing the technology to reduce emissions of GHG and sulfur dioxide (SO2) while at the same time increasing the investments in renewable energy plants that need to be substitute capacities for coal-fired power plants in order to gradually reduce the production from coal and to achieve the EU trends in these terms;
b) the construction of new coal-fired thermal power plants with fully applied technologies for reducing GHG and SO_2 emissions, with minimal investments in renewable energy plants (up to the fulfillment of the national quotas);
c) investment in new plants for electricity production based on renewable energy sources (sun and wind energy) without any rehabilitation of the existing or construction of the new coal-fired thermal power plants.

The research results were expected to provide guidance on which of the above three scenarios would be the most optimal for further development of the electricity sector in the developing countries. The expected outcome of the research was the confirmation of the scenario “a)”, as the assumed best way for developing countries. The scenarios “b)” and “c)” were the next possible realistic results listed respectively in the likelihood of achievement.

Apart from the results of the research obtained from the economic and financial analysis, the proposal of the best scenario is also significantly impacted by the views of the BiH government, the local population, the Energy Community, the EU, and the other stake-holders as well.

2. EU Legal Framework for Energy and Climate Change

Historically, the use of fossil fuels (oil, gas and coal) in energy production has had a dominant role worldwide for many years. This dominant role has remained to the present day, but in the last few decades there has been a significant shift in the use of fossil fuels as a primary energy source, primarily because of their negative impacts like global warming and climate change.

The reason behind this dominance is that fossil fuels have always been suitable for use as primary fuels in energy production because they are relatively easily accessible for economically profitable exploitation. Furthermore, they could be stored for later use, while at the same time they could be relatively easily transported around the world and spent in places of greatest need for energy.

The CO_2 emissions, arising from the use of fossil fuels in industry and transport and from the furnaces during the combustion of fossil fuels as a primary energy source, have been declared the main cause for global warming of the planet and evident climate change. In addition to CO_2, the combustion chambers emit a significant amount of SO_2, nitrogen oxide (NO_x) and solid particles, which all have a negative effect on health of the population and the environment.

The consequences of global warming and climate change on the planet were the latest alarm for the radical shift of humanity in search for sustainable development policies in all spheres of life in order to save the planet Earth. This implied a radical reduction in the use of fossil fuels in energy production, industry, heating/cooling systems and transport. An alternative to this reduction in the use of fossil fuels was the introduction of new technologies for the production of energy from renewable energy sources and the rationalization of consumption through the implementation of energy efficiency measures and savings in energy consumption.

With its paper titled “A Framework Strategy for a Resilient Energy Union with a Forward-Looking Climate Change Policy” (European Commission, 2015), the EU provided a complete roadmap to fight the climate change and contribute to the prevention of global warming in the EU and beyond.

One of the EU's most important goals defined by the framework strategy for a resilient energy union is to provide all EU citizens and businesses with secure and sustainable energy supply at competitive prices with a simultaneous implementation of the established climate policy measures.

The European Court of Auditors (2017) stated that one of the main challenges of the EU is to meet the demands for energy, while simultaneously reducing GHG emissions, since energy production is responsible for 79% of the total EU GHG emissions, and that these emissions are in the most part created through the combustion and transformation of fossil fuels (p. 12).

It is clear that the EU has identified the main causes of greenhouse gas emissions and recognized the need to replace the fossil fuels with renewable energy sources, as a key challenge in efforts to mitigate the effects of climate change.

The European Court of Auditors (2017) also stated that “a resilient Energy Union is a key priority of the European Commission and its Energy Union strategy serves as a set of guidelines in achieving this goal. For these purposes, the EU allocated at least 20% of its 2014-2020 budget on climate action, in other words almost 212 billion euro” (p. 12).

By committing a significant amount of its budget for the climate and environment related strategies, it is obvious that the EU has firmly opted to be the leader in mitigating the effects of climate change in the world. Figure 1 displays the main dimensions needed for creating the strong and sustainable energy union.

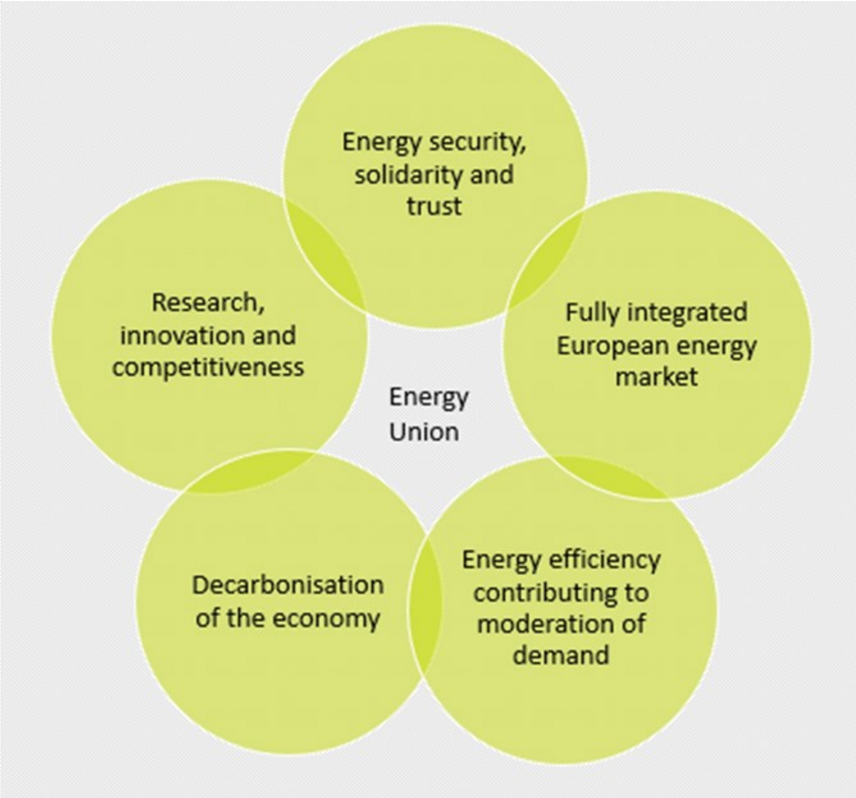

Figure 1. Dimensions of the Energy Union.

This figure illustrates five closely related dimensons needed for a resilient Energy Union. Adapted from “EU Action on Energy and Climate Change”, by the European Court of Auditors, 2017, p. 13, Luxembourg, LU: Publications Office of the European Union.

Figure 1 suggests that the EU has set out clear directions and goals that lead to the provision of sufficient amounts of sustainable energy through these main interconnected dimensions. These five dimensions have become a tool and a roadmap for the fulfillment of the EU commitments. In the meanwhile the EU leaders institutionalized the adopted climate and energy targets that the EU needs to reach by 2020, 2030 and 2050, respectively (European Court of Auditors, 2017, p. 78).

The EU's stated goals by the year 2020 are also known as "20-20-20 targets", and the EU has undertaken the obligation to achieve the targets stated in Table 1.

Table 1

The EU Energy Targets by 2020, 2030 & 2050

Target Year	Targets
2020[a]	- Reduction of GHG emissions by at least 20% (compared to levels from 1990) - 20% share of renewable energy in EU energy consumption - Improvement of energy efficiency by 20% in relation to predictions of future energy consumption
2030[b]	- Reduction of GHG emissions by at least 40% (compared to levels from 1990) - 27% share of renewable energy in EU energy consumption - Improvement of energy efficiency by at least 27% in relation to predictions of future energy consumption. This will be reviewed by 2020, having in mind an EU level of 30%.[c]
2050[d]	- Reduction of GHG emissions by 80-95% (compared to levels from 1990)

Note. [a]Data for the year 2020, adapted from “20 20 by 2020 Europe’s Climate Change Opportunity”, by Commission of the European Communities, 2008, COM(2008) 30 final, Brussels, BE, pp. 2 & 8.

[b]Data for the year 2030 adapted from “A Policy Framework for Climate and Energy in the Period from 2020 to 2030”, by European Commission, 2014, COM(2014) 15 final, Brussels, BE, pp. 5-6.

[c]Data adapted from “European Council Conclusions”, by European Council, 2014, EUCO 169/14, Brussels, BE, p. 5.

[d]Data for the year 2050 adapted from “Opinion of the European Economic and Social Committee on the ‘Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions on a roadmap for moving to a competitive low carbon economy in 2050’ ”, by Adams, R. and Zboril, J., 2011, *Official Journal of the European Union*, Brussels, BE, p. 110.

Figure 2 shows the trend in total emissions of GHG of the 28 EU member states in the 1990-2015 period, including international air traffic. In 2015, the total emissions were 4.45 gigatons of CO_2. Compared to the reference year of 1990 when the total emissions were 5.72 gigatons, a considerable reduction by 22.21% was achieved (European Environment Agency, 2018).

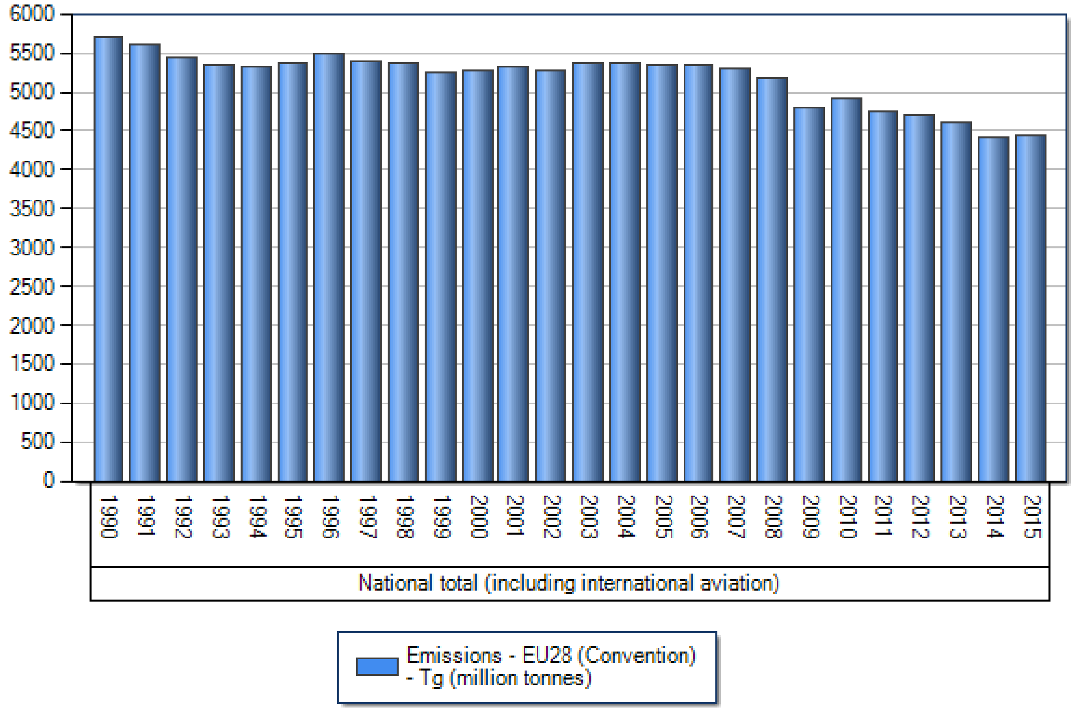

Figure 2. Total Greenhouse Gas Emissions in the EU from 1990 to 2015.

This figure shows the trend in total annual emissions of GHG in the 28 EU member states, in the 1990-2015 period. The emissions are expressed in million tons (Tg). Adapted from "EEA Greenhouse Gas - Data Viewer" by European Environment Agency, 2016, Copenhagen, DK, p. 5, retrieved from https://www.eea.europa.eu/downloads/f4269fac-662f-4ba0-a416-c25373823292/1527778508/greenhouse-gases-viewer.pdf

The countries of the Southeastern Europe and the members of the UN that are yet to join the EU: Albania, Bosnia and Herzegovina, Montenegro, Macedonia and Serbia have all pledged to join the world's leading countries in their efforts to quickly and efficiently reduce GHG emissions. In addition, by taking over the EU directives in the field of renewable energy sources, energy efficiency and reducing GHG emissions, these countries have committed themselves to meet the set EU targets in these areas.

Section 2.1 will present the main Directives and Regulations set by the EU as the obligations in the energy sector reforms set in front of the countries that aspire to join the EU. Sections 2.2 and 2.3 will introduce the international organization Energy Community and its objectives for renewable energy respectively. Section 2.4 elaborates the status of renewable energy in BiH in relation to corresponding EU regulations, while section 2.5 provides the statistical overview of the installed capacities and production from renewable sources in BiH.

2.1 EU Binding Directives and Regulations

The EU binding directives, known under the Latin name *acquis communautaire* represent the total accumulated EU law based on a set of legal norms and practices derived from court decisions, and it has a binding effect in all EU countries. This means that any country that wants to join the EU is obligated to align its legislation with the EU acquis in all areas defined in negotiating chapters in the EU accession process.

The most important acts of the EU acquis communautaire are Directives and Regulations, which are legally binding in all EU member states. According to Communication department of the European Commission (2018), The EU member states have a duty to implement the Directives, but can themselves choose the methods of implementation, while the Regulations must be implemented both in content and form, as in the original form (para. 2 & 3).

In addition to the Directives and Regulations, three additional types of documents are used: Decisions, Recommendations and Opinions. The decisions are legally binding only for a particular EU member state or individual company to whom they are addressed, while Recommendations and Opinions are not mandatory for implementation and serve rather as a form of suggestions and guidelines without legal consequences (Communication department of the European Commission, 2018, para. 4, 5 & 6).

When it comes to energy, the acts of the acquis communautaire regulate the following areas:

- electricity,
- gas,
- oil
- environment,
- renewable energy,
- energy efficiency,
- statistics.

Table 2 shows the directives and regulations on the above listed areas that have arisen in the process of establishing a legal framework in the EU.

Table 2

The EU Directives and Regulations per Sector

Sector	Directive / Regulation
Electricity	- Directive concerning common rules for the internal market in electricity (p. 53) - Regulation on conditions for access to the network for cross-border exchanges in electricity (p. 111) - Directive concerning measures to safeguard security of electricity supply and infrastructure investment (p. 137)
Gas	- Directive concerning common rules for the internal market in natural gas (p. 149) - Regulation on conditions for access to the natural gas transmission networks (p. 211) - Directive concerning measures to safeguard security of natural gas supply (p. 237)
Oil	- Directive imposing an obligation on Members States to maintain minimum stocks of crude oil and/or petroleum products (p. 249)

(*continued*)

Sector	**Directive / Regulation**
Envinronment 	- Directive on the assessment of the effects of certain public and private projects on the evinronment, as amended (p. 275) - Directive relating to a reduction in the sulphur content of certain liquid fuels (p. 293) - Directive on the limitation of emisions of certain polutants into the air from large combustion plants (p. 303) - Directive on the conservation of wild birds (p. 329)
Renewable Energy 	- Directive on the promotion of the use of energy from renewable sources (p. 341)
Energy Efficiency 	- Directive on energy end-use efficiency and energy services (p. 407) - Directive on the indication by labelling and standard product information of the consumption of energy and other resources by energy-related products (p. 433) - Directive on the energy performance of buildings (p. 447)
Statistics 	- Directive concerning a Community procedure to improve the transparency of gas and electricity prices charged to industrial end-users (p. 477) - Regulation on energy statistics (p. 489)

Note. Adapted from "The Energy Community Legal Framework 3rd Edition", by Energy Community, 2013, Vienna, AT: Energy Community Secretariat.

Directives and Regulations from Table 2 are the main drivers of energy sector reforms in the EU member states and other non-EU European countries that aim to become the full-time members.

2.2 The Energy Community

“The Energy Community is an international organisation which brings together the European Union and its neighbours to create an integrated pan-European energy market. The organisation was founded by the Treaty establishing the Energy Community signed in October 2005 in Athens, Greece, in force since July 2006. The key objective of the Energy Community is to extend the EU internal energy market rules and principles to countries in South East Europe, the Black Sea region and beyond on the basis of a legally binding framework“ (Energy Community, 2017a, para. 1).

The Energy Community Secretariat is an operational body that operates continuously in monitoring the implementation of the Treaty establishing the Energy Community and provides operational, technical, legal and any other support in the organization of all processes, activities and events concerning contracting parties.

Energy Community consists of 10 members: the EU on one hand, and nine contracting parties on the other: Albania, Bosnia and Herzegovina, Former Yugoslav Republic of Macedonia, Georgia, Kosovo, Moldova, Montenegro, Serbia and Ukraine. In addition to the members, there are also three countries with the status of observers: Armenia, Norway and Turkey. BiH officially became a member of the Energy Community in 2006 by signing the treaty establishing the Energy Community. Figure 3 shows the map of the Energy Community.

Figure 3. Map of the Energy Community.

This figure shows all the countries involved in the Energy Community, either as members (The EU countries and contracting parties) or as observers (Armenia, Norway and Turkey). The contracting parties marked with yellow are: Albania, Bosnia and Herzegovina, FYR of Macedonia, Georgia, Kosovo, Moldova, Montenegro, Serbia and Ukraine. Adapted and modified from "Who We Are" by Energy Community, 2017b. Retrieved from https://www.energy-community.org/aboutus/whoweare.html

According to the Energy Community (2017a), the treaty establishing the Energy Community defined the following mission:

- "establishment of a stable regulatory and market framework capable of attracting investment in power generation and networks;
- creation of an integrated energy market allowing for cross-border energy trade and integration with the EU market;
- enhancement of the security of supply to ensure stable and continuous energy supply that is essential for economic development and social stability;
- improvement of the environmental situation in relation with energy supply in the region and foster the use of renewable energy and energy efficiency; and

- development of competition at regional level and exploitation of the economies of scale" (para. 2).

The Secretariat of the Energy Community actively initiates, organizes, supervises and directs all processes in the countries that have signed the Treaty establishing the Energy Community in the function of fulfilling the tasks of the Energy Community. This implies an effective measurement of the achieved level of completed tasks and the related objectives of individual member countries of the Energy Community as well as periodic reporting.

In line with the ongoing development and improvement of the acquis communautaire, the Secretariat of the Energy Community encourages the member states of the Energy Community to rapidly accept, transpose into national legislation and implement the amended or revised EU legislation. Primarily, the focus of the Secretariat of the Energy Community is to ensure that the goals set by year 2020 are reached.

More recently, the EU bodies have initiated a process of defining targets in terms of GHG emissions, energy efficiency and renewable energy by 2030. All member countries of the Energy Community will, based on the previously set guidelines from the Energy Community Secretariat, have to develop their own national energy and climate plans.

In the following period, the priority in the Energy Community will be the complete implementation of the so-called Third Energy Package and implementation of the *Memorandum of Understanding of the West Balkan six (WB6) initiative*[1]. The framework of the WB6 initiative summarizes a roadmap for the establishment of a regional electricity market, mechanisms for linking markets, as well as balancing and cross-border capacity utilization (WB6 Energy Community, 2016, pp. 1-3).

[1] The initiative for strengthening the regional cooperation between six Western Balkan countries (which are all members of the Energy Community): Albania, Bosnia and Herzegovina, FYR of Macedonia, Kosovo, Montenegro and Serbia.

2.3 Objectives of the Energy Community for Renewable Energy

By signing the Energy Community Treaty, the Member States of the Energy Community have undertaken the obligation to transpose Directive 2009/28 / EC which promotes the use of energy from renewable sources (European Parliament and the Council of the European Union, 2009, p. 16).

In essence, by adopting this directive, the EU has established policies to promote the production of electricity by using renewable energy sources to ensure effective environmental protection, reliability, safety and quality in the production of sufficient amounts of electricity and reduction of dependence on imports and use of fossil fuels.

The Ministerial Council of the Energy Community, by its decision from 2012, has committed itself to the implementation of Directive 2009/28 / EC, which, among other things, sets out national targets for renewable energy sources which the Energy Community member states must realize by 2020 (Energy Community Ministerial Council, 2012, p. 2).

In accordance with this directive, all the member states of the Energy Community have adopted national plans for the use of energy from renewable energy sources. The targets of the member states of the Energy Community for renewable energy are shown in Table 3.

Table 3

Renewable Energy Objectives of the Energy Community Member States

Contracting party of the Energy Community	Share of renewable energy sources in total gross electricity consumption in reference year 2009	Target share of renewable energy sources in total gross electricity consumption in 2020
Albania	31.2 %	38.0 %
Bosnia and Herzegovina	**34.0 %**	**40.0 %**
FYR of Macedonia	21.9 %	28.0 %
Kosovo	18.9 %	25.0 %
Moldova	11.9 %	17.0 %
Montenegro	26.3 %	33.0 %
Serbia	21.2 %	27.0 %
Ukraine	5.5 %	11.0 %

Note. Georgia is the only contracting party of the Energy Community not listed in the table because of the unavailability of the data. Adapted and modified from "Renewable Energy Action Plans and Regulations to Harmonise with EU Directives", by IRENA, 2013, p. 4, retrieved from http://www.irena.org/-/media/Files/IRENA/Agency/Events/2013/Jan/12_1/Background_Paper-A.pdf?la=en&hash=C78F0A0524E2CA415B11E7E25EEC23447E90C052

Analyses of the current situation in the use of renewable sources in the member states of the Energy Community indicate that the set goals in most countries will not be fully achieved despite the fact that many of the member states have significant potentials and opportunities for significant energy production from renewable sources. The reasons that may affect the realization of the set objectives are various, starting from an incomplete legislative and legal framework to the inability to significantly attract capital of foreign and domestic investors for investment in production capacities based on renewable energy sources.

2.4 Status of Renewable Energy in Bosnia and Herzegovina

In 2016, Bosnia and Herzegovina adopted the *National Renewable Energy Action Plan of Bosnia and Herzegovina (NREAP BiH)* in accordance with the requirements of Directive 2009/28 / EC on the promotion of the use of energy from renewable sources. NREAP BiH has established sectoral objectives and set specific goals in the areas of heating & cooling, electricity and transport. Table 4 shows the target values for the share of renewable sources in BiH in these sectors.

Table 4

Renewable Energy Targets in BiH per Sector

Sector	Share of renewable energy sources in total gross electricity consumption in reference year 2009	Target share of renewable energy sources in total gross electricity consumption in 2020	Increase in the share of renewable sources in total gross consumption in 2020
Heating & cooling	43.3 %	52.4 %	9.1 %
Electricity	50.3 %	56.9 %	6.6 %
Transport	0.9 %	10.1 %	9.2 %
TOTAL	**34.0%**	**40.0 %**	**6.0 %**

Note. Data adapted from "*National Renewable Energy Action Plan of Bosnia and Herzegovina (NREAP BiH)*", by Council of Ministers of Bosnia and Herzegovina, 2016, p. 16.

In Table 4, the share of renewable sources in total gross consumption in the reference year 2009 of the transport sector refers to the share of electricity in rail transport. Considering that the first electric cars have already appeared in BiH with the tendency of increasing their number in use, the share of renewable sources in the transport sector in 2020 is projected at 10%, which corresponds to the target value in the EU. However, objectively, by 2020 BiH will not be able to achieve the target value of 10% in the transport sector due to a number of obstacles, starting from the legal framework and a lack of incentive measures for the use of energy from renewable sources in the transport sector to technical and technological barriers in the production, use and control of bio fuel.

The sectoral target values listed in Table 4 of the share of renewable sources in BiH in total gross consumption in 2020 are not fixed and have been determined so as to ensure the overall target of 40% of the share of renewable sources in total gross consumption in 2020.

In order to achieve the target values listed in Table 4, the share of renewable sources in total energy consumption by sectors, when expressed in a common energy unit should reach the values shown in Table 5. The measure unit is the *kiloton of oil equivalent* (ktoe) that represents the amount of energy released from burning 1 thousand tons of oil.

Table 5

Target Shares in Renewable Energy in BiH in ktoe Unit

Sector	**Share of renewable energy sources in total gross electricity consumption in reference year 2009**	**Target share of renewable energy sources in total gross electricity consumption in 2020**
	(ktoe)	(ktoe)
Heating & Cooling	805.8	1,085.2
Electricity	495.2	741.4
Transport	5.9	113.9
TOTAL	**1,306.9**	**1,940.5**

Note. ktoe = kiloton of oil equivalent. Data adapted from "*National Renewable Energy Action Plan of Bosnia and Herzegovina (NREAP BiH)*", by Council of Ministers of Bosnia and Herzegovina, 2016, p. 16.

It is worth noting that NREAP BiH has established the policies and measures for achieving these predetermined targets, presented in Table 4 and Table 5.

2.5 Statistical Overview of the Installed Capacities and Production from Renewable Sources in Bosnia and Herzegovina

Thanks to its geographical position and the natural richness of water and other natural resources, BiH has, on the one hand excellent predispositions for the development of electricity generation from renewable sources. On the other hand, despite such natural resources, due to a number of political, legal and institutional obstacles, BiH has still not been able to take sufficient advantage of all these potentials in the function of sustainable economic development and the growth of society as a whole.

In addition to evident water resources, significant opportunities for the production of electricity from renewable sources can be provided through the construction of the PV power plants, wind power plants and wind farms, biomass and biogas power plants, as well as energy production based on fuels coming from residues in agricultural production.

Practically, by the end of 2017, in Bosnia and Herzegovina, the only significant progress was made in the use of renewable energy of water through the construction of small hydropower plants on numerous watercourses, and to some extent in the use of sun energy through the construction of a certain number of PV power plants. However, the number of power plants based on wind energy, biomass and biogas can still be quantified by a single-digit number. For instance, it was not until the beginning of 2018 when “Mesihovina”, the first wind farm in Bosnia and Herzegovina was put into operation.

In order to get an overview of the energy sector on national level, it is important to stress out that politically, BIH is divided into two entities: the Federation of Bosnia and Herzegovina (FBiH) and the Republic of Srpska (RS), and in addition, there is also the self-governing Brcko District, which is not a part of any of the two entities. The entities and Brcko District all have their own governments. So the energy policy in BiH is for the most part under the jurisdiction of the entities and Brcko District, and, to a lesser extent, under the jurisdiction of the state of BiH, through the Council of Ministers. For the most part, the data on the energy sector are published on entities’ and not on the national level. Table 6 shows the status of completed renewable energy projects in BiH, up until 2017, classified by the type of primary renewable source used in electricity generation.

Table 6

Finished Renewable Energy Projects in BiH, up until 2017

Type of power plant	FBiH[a] Total number of plants	FBiH[b] Installed capacity (MW)	RS[c] Total number of plants	RS[d] Installed capacity (MW)	BiH Total number of plants	BiH Installed capacity (MW)
Hydro power plants	53	50.21	24	53.30	77	103.51
Wind farms	1	0.30	0	0.00	1	0.30
Biomass	0	0	1	0.24	1	0.24
PV power plants	138	611.54	48	6.22	186	617.76
Other	1	0.43	1	0.99	2	1.42
Cogeneration	0	0	0	0	0	0
Total	**193**	**662.48**	**74**	**60.75**	**267**	**619.18**

Note. MW – Megawatt.

[a,b]Data adapted from "*Registar projekata* [Project register]", by Operator for renewable energy sources and efficient cogeneration, 2018, [data file] retrieved from http://operatoroieiek.ba/wp-content/uploads/2018/05/Web-Registar20180518.rar

[c,d]Data adapted from "*Proizvodna postrojenja koja su ostvarila pravo na podsticaj* [Production Plants with Achieved Right on Guaranteed Redemption Prices]", by Regulatory Commission for Energy of Republic of Srpska, 2018, [data file] available on http://www.reers.ba/lat/node/5195

It is also worth noting that there is a considerable number of currently ongoing projects regarding the electricity production from renewable energy in BiH. Table 7 shows the status of ongoing renewable energy projects in BiH, classified by the type of primary renewable source used in electricity generation.

Table 7

Ongoing Renewable Energy Projects in BiH

Type of power plant	FBiH[a] Total number of plants	FBiH[b] Installed capacity (MW)	RS[c] Total number of plants	RS[d] Installed capacity (MW)	BiH Total number of plants	BiH Installed capacity (MW)
Hydro power plants	38	49.57	23	51.96	61	101.53
Wind farms	18	644.72	0	0	18	644.72
Biomass	5	123.72	0	0	5	123.72
PV power plants	186	782.20	6	2.24	192	784.44
Other	0	0	0	0	0	0
Cogeneration	0	0	0	0	0	0
Total	**247**	**1,600.21**	**29**	**54.20**	**276**	**1,645.41**

Note. MW – Megawatt.

[a,b]Data adopted from "*Registar projekata* [Project register]", by Operator for renewable energy sources and efficient cogeneration, 2018, [data file] retrieved from http://operatoroieiek.ba/wp-content/uploads/2018/05/Web-Registar20180518.rar

[c,d]Data adopted from "*Proizvodna postrojenja koja su ostvarila pravo na podsticaj* [Production Plants with Achieved Right on Guaranteed Redemption Prices]", by Regulatory Commission for Energy of Republic of Srpska, 2018, [data file] available on http://www.reers.ba/lat/node/5195

Out of all ongoing projects related to renewables, Table 7 shows that the biggest share in the increase in the total installed capacity in BiH is planned to be achieved through the construction of new PV power plants and wind farms, which further emphasizes the need to address and analyze the feasibility of construction of such plants in BiH.

According to the Independent System Operator in Bosnia and Herzegovina (2018), the total electricity production in the transmission system of BiH in 2017 was 14,627 Gigawatt hours (GWh) (p. 2). Figure 4 breaks down the total electricity production into types of sources it came from. Out of the total electricity produced, 74% came from thermal power plants and 26% from hydro power plants.

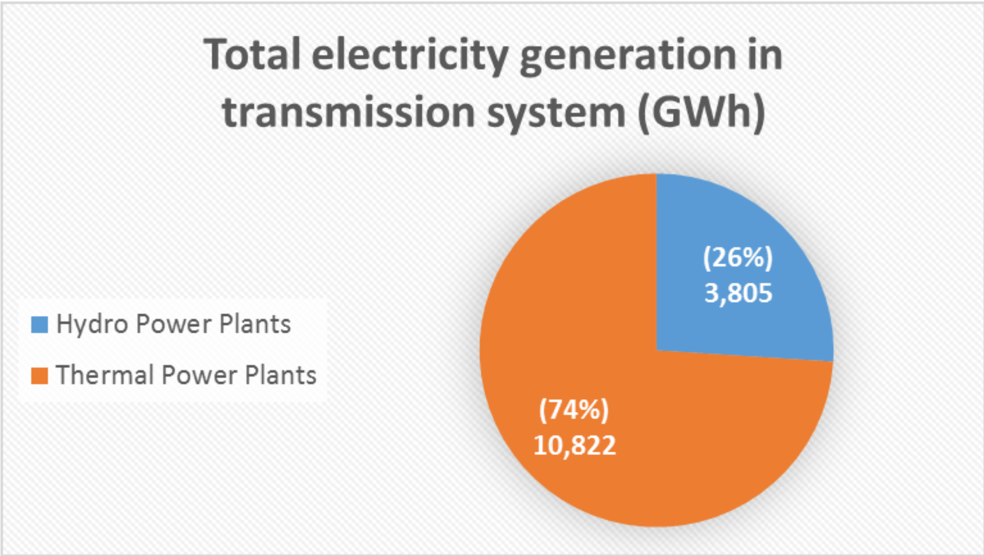

Figure 4. Total Electricity Generation in the Transmission System of BiH in 2017. This figure breaks down the total electricity generation in 2017, into the shares of electricity coming from hydro and thermal power plants, being the only two types of power plants directly producing the electricity in the transmission system of BiH. The values are expressed in Gigawatt hour (GWh) unit. Adapted and modified from "Report on Power Flows in the Transmission System of Bosnia and Herzegovina in 2017", by Independent System Operator in Bosnia and Herzegovina, 2018, p. 2, Sarajevo, BA: NOSBiH.

As we can see from Figure 4, out of the total 14,627 GWh of produced electricity in 2017 in BiH, 3,805 GWh or 26% were produced in large and small hydro power plants. Electricity produced in hydropower plants also belongs to the energy produced from renewable sources, and it can be concluded that, by 2020, with additional production from PV power plants, wind farms, bio energy and bio gas plants, BiH has a realistic chance of reaching a designated quota of 40% of the share of electricity consumption from renewable sources, in the total consumption of electricity.

In addition to the sources of the total electricity generated in the transmission network, Figure 5 breaks down the total amount of electricity available on the transmission network into the shares of electricity produced in the system, electricity injected from the distribution network and electricity received from the neighboring systems.

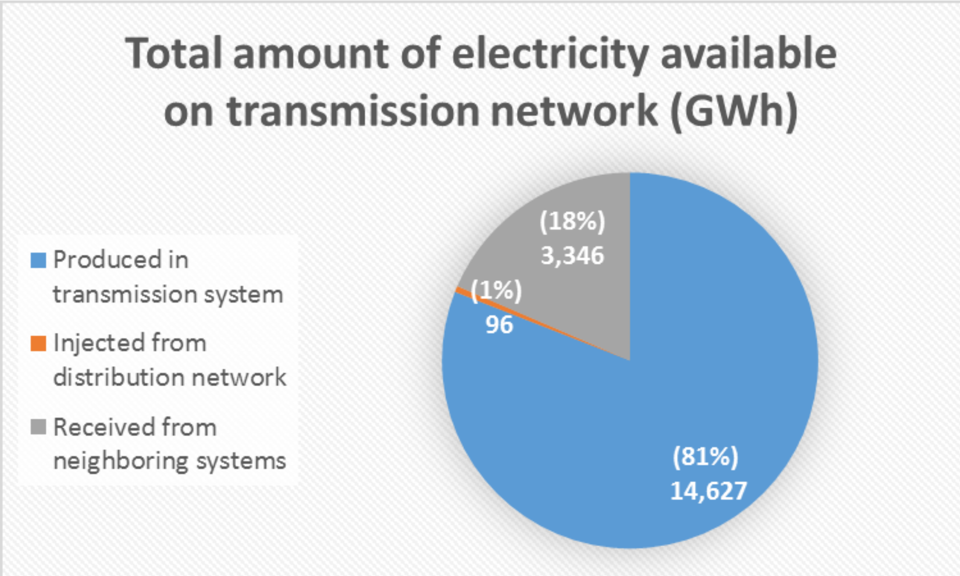

Figure 5. Total Amount of Electricity Available on the Transmission Network of BiH in 2017.

This figure breaks down the total amount of electricity available on the transmission network of BiH in 2017 by showing in what amount the electricity comes from the production in the transmission system, how much electricity was injected from the distribution network and how much was received from neighboring systems. Adapted and modified from "Report on Power Flows in the Transmission System of Bosnia and Herzegovina in 2017", by the Independent System Operator in Bosnia and Herzegovina, 2018, p. 2, Sarajevo, BA: NOSBiH.

As we can see in Figure 5, the amount of electricity available on the transmission network of BiH that was injected from the distribution network was 96 GWh. The amount of electricity of 96 GWh from the distribution network in fact represents the electricity produced from renewable sources (except large hydroelectric power plants) in power plants connected to the distribution network. So taking a look at this number in relation to the total electricity produced in large hydropower plants and thermal power plants of 14,627 GWh, the share of electricity from other renewable energy sources in BiH other than large hydropower plants (small hydropower plants, PV plants, biofuel and wind power plants) amounts to just 0.66%. This percentage clearly shows that, except for the exploitation of hydro potentials of water, BiH has not yet done enough to build capacities for electricity production from renewable energy sources (solar, wind, biomass and biogas), despite the fact that, for this development, the country has a number of comparative advantages.

3. EU Historical Trends in Electricity Production

Statistical Office of the European Communities (Eurostat), as the leading EU institution for statistics, has developed unique and unified methods for collecting and statistical processing of the data in energy sector. It is this uniqueness and unification that has enabled a very high comparability of the data of the EU 28 member states as well as the unification of energy statistics and reports in the field of energy and other areas that are subject of statistical processing.

Based on data from the 28 EU member states, among other sets of data, Eurostat (2017) published tabular reviews and diagrams of trends for primary energy production, import and export of energy, total energy consumption within the EU states, and the structure and extent of participation of primary fuels for energy production. The data processed refer to the 1990-2015 period.

Figure 6 shows the primary energy production in the EU 28 Member States for the period 1990-2015, expressed in ktoe unit.

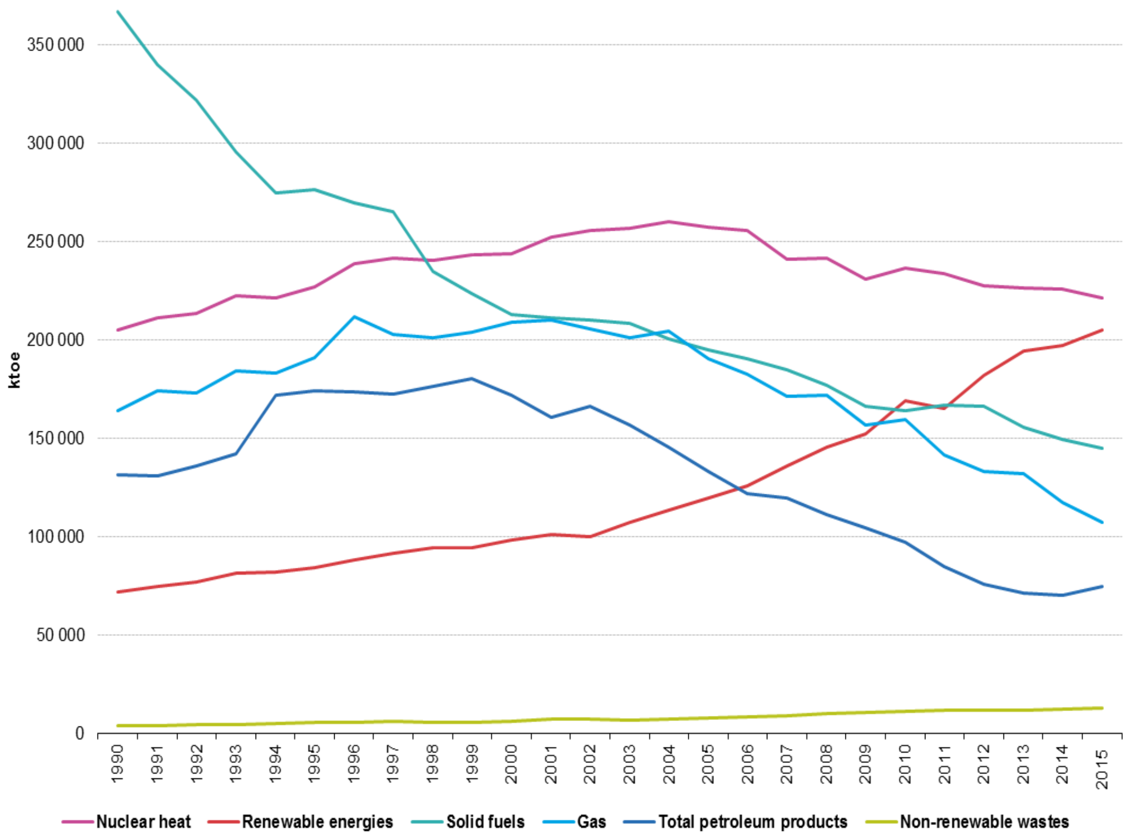

Figure 6. Primary Energy Production in the EU from 1990 to 2015.

This figure shows the trends in primary energy production in the 28 member states of the EU, for the period between 1990 and 2015. The values are expressed in ktoe unit. Adapted from "Energy Trends", by Eurostat, 2017, retrieved from http://ec.europa.eu/eurostat/statistics-explained/index.php?title=File:Primary_energy_production,_EU-28,_1990-2015,_ktoe_final.png

By analyzing Figure 6, we can clearly notice that two trends stand out. One is a large and continuous decline in the use of solid fuels as a prime energy source and the other is a strong growth in the use of renewable energy sources over the course of 15 years. Back in 1990, coal was by far the most dominant primary energy source. The total amount of solid fuels used in energy production in 1990 was above 350,000 ktoe, but over the course of years, in 2015, it fell to less than 150,000 ktoe, which means that the use of solid fuels was cut in more than a half in just 15 years. The main reason for the declining trend is the introduction of policies to reduce GHG emissions in the function of environmental protection. In addition, gas and total petroleum products also recorded a moderate decline in use. However, the total amount of renewable energy sources used in energy production increased from around 70,000 in 1990 to more than 200,000 ktoe in 2015, being second only to nuclear heat, as the most widely used primary energy source in the EU in 2015. These trends go in line with the commitments of the 28 EU member states to fight against the global warming and climate change and clearly show that the EU energy policies were and still are successful and should be followed and adopted by the developing countries as well. Figure 7 shows the gross electricity production by fuel in the EU for the same period.

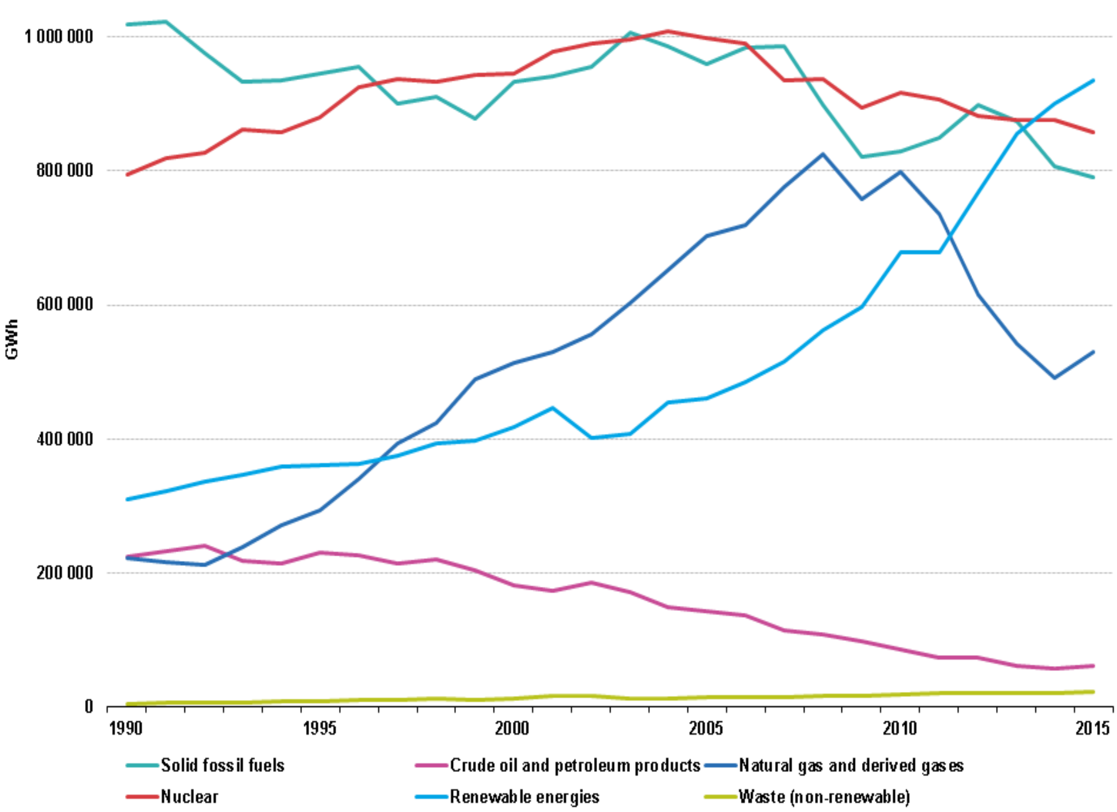

Figure 7. Gross Electricity Production by Fuel in the EU from 1990 to 2015.
This figure shows the trends in total electricity production in GWh, by the type of primary fuel, in the 28 member states of the EU in the period between 1990 and 2015. Adapted from "Electricity and Heat Statistics", by Eurostat, 2017a, retrieved from http://ec.europa.eu/eurostat/statistics-explained/index.php?title=File:Gross_electricity_production_by_fuel,_GWh,_EU-28,_1990-2015_F1.png

Figure 7 clearly shows that in 2015, solid fossil fuels, besides nuclear energy, still had one of the biggest shares in the total gross electricity production in the EU. However, the importance of the renewable sources for electricity production had grown drastically. By 2015, the share of renewable energy sources in the total gross electricity production in the EU increased almost three times in comparison to the reference year 1990 and became the source with the biggest share in gross electricity production in the EU. A particularly rapid growth trend in electricity production from renewable energy sources can be seen after in the last decade. According to IRENA (2017), such a significant increase in the total gross output is largely a result of the fall in prices of certain types of technology and equipment for the production of electricity from renewable sources, as well as the growing importance and existence of systems of incentives for investment in the production of electricity from renewable sources (p. 2). In addition, the undertaken commitments to achieve the objectives of limiting global warming and protecting the environment, were the additional motive and incentive for expansion of production from renewable energy sources.

Figure 8 provides a slightly different view of the electricity production by fuel in order to display the volume and total share of each of the primary fuels in total gross electricity production in the EU, in comparison and in relation to each other.

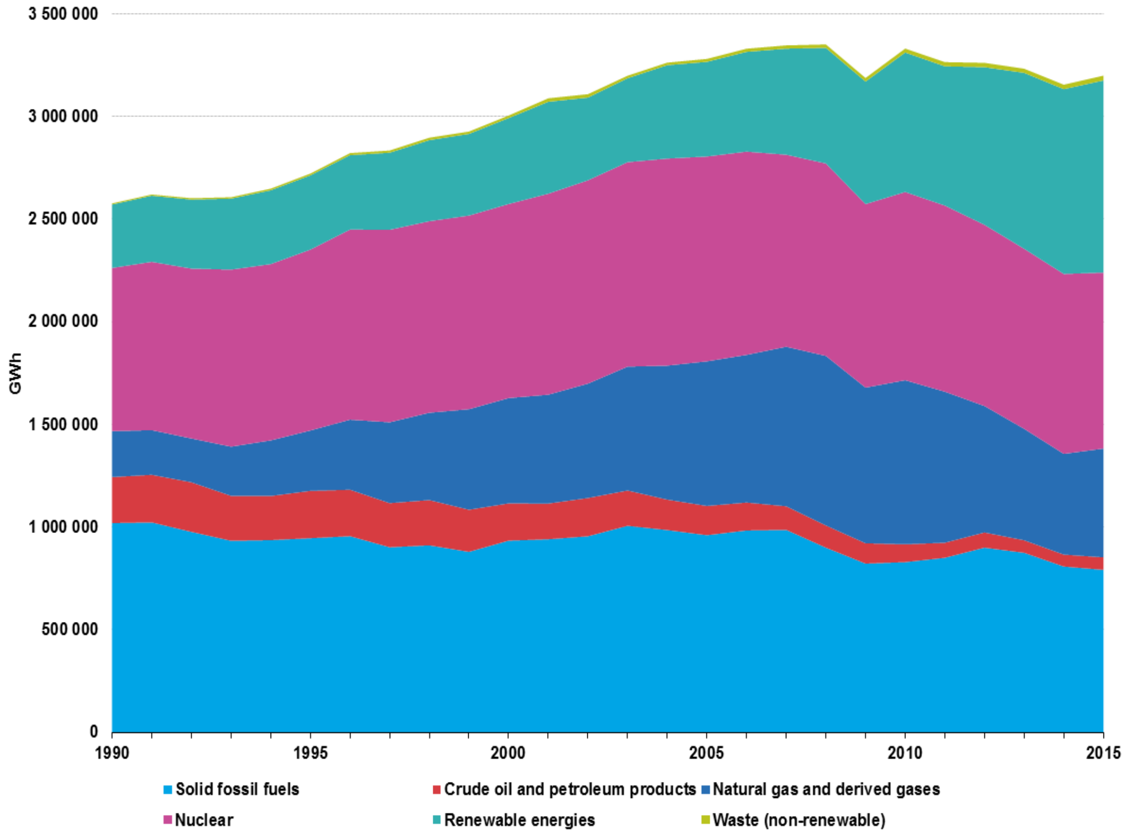

Figure 8. Volume of Electricity Production by Fuel in the EU from 1990 to 2015. This figure shows the trends in volume and total share of primary fuels for electricity production in a direct comparison between each other, in the 1990-2015 period in the 28 member states of the EU. The values are expressed in GWh unit. Adapted from "Electricity and Heat Statistics", by Eurostat, 2017b, retrieved from http://ec.europa.eu/eurostat/statistics-explained/index.php?title=File:Gross_electricity_production_by_fuel,_GWh,_EU-28,_1990-2015_new.png

Analyzing the trends shown in Figure 8, it is worth noting that the volume and share of electricity production from solid fossil fuels as well as from crude oil and oil derivatives in the period from 1990 to 2015 in the EU, have a steady downward trend, while the production from renewable sources recorded almost a continuous growth. The production of electricity from nuclear power plants had a growing trend until 2006, after which a considerable downward trend towards 2015 was recorded. One of the reasons for this change in the trend is the introduction of the policy of gradual and eventually complete closure of nuclear power plants and replacement of their electricity production with the production from renewable sources.

Sections 3.1 and 3.2 will break down the overall trends in electricity production in the EU into trends of production coming from conventional power plants and power plants based on renewable energy, respectively. Section 3.3 shows the trends of change in the structure of electricity production in the EU. Section 3.4 compares the overall general costs of electricity production between different technologies, while section 3.5 provides the overview of LCOE for conventional, PV and wind power plants, as one of the most used tools for determining the costs of electricity production.

3.1 Trends of Electricity Production from Conventional Power Plants in the EU

Conventional power plants include power plants that use non-renewable resources such as coal, oil, gas and nuclear energy as primary fuels for the production of electricity. As mentioned earlier in the thesis, the intentions of the EU environment and energy policies are directed towards the reduction in the use of such resources in the electricity production. Figure 9 shows that these efforts have shown results, where each type of conventional fuels have recorded a downward trend in their use.

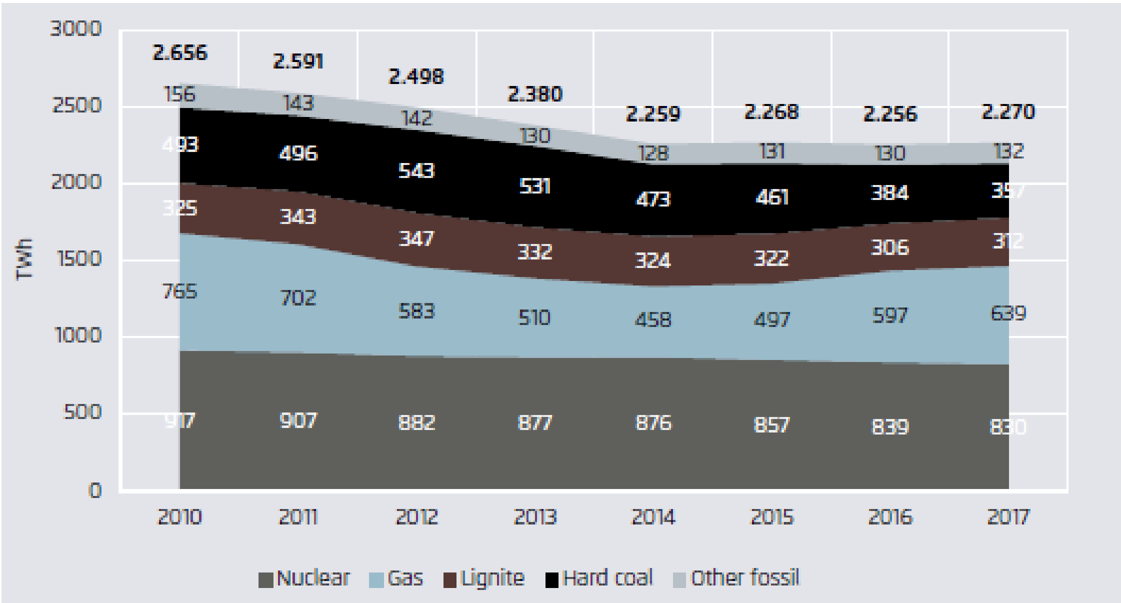

Figure 9. Conventional Electricity Production by Fuel in the EU from 2010 to 2017. This figure shows the trends in total electricity production per type of non-renewable fuels in the period between 2010 and 2017 in the 28 member states of the EU. The values are expressed in Terawatt Hour (TWh) unit. Adapted from “The European Power Sector in 2017. State of Affairs and Review of Current Developments”, by Agora Energiewende

and Sandbag, 2018, p. 21, retrieved from https://www.agora-energiewende.de/fileadmin2/Projekte/2018/EU_Jahresrueckblick_2017/Agora_EU-report-2017_WEB.pdf

Data in Figure 9 clearly show the steady declining trends in the production of electricity from conventional (fossil) fuels. A continuous fall in total electricity produced by all non-renewable fuels in conventional power plants have been recorded at the end of every year apart from 2015 (only slight growth though). Out of all fuel sources in conventional power plants, nuclear energy had and still has the biggest share in the total electricity production. However, there is a steady decline in production from nuclear power plants. Also, the production of electricity from heavy coal and lignite in 2017 compared to 2010 is lower by about 28% for heavy coal and about 4% for lignite. In the production of electricity from natural gas as an energy source, until 2015, there was also a slightly declining trend. However, in the period 2015-2017, there was an increase in production from natural gas, from produced 497 Terawatt Hours (TWh) in 2010 to 639 TWh in 2017 or by approximately 29%. An increase in natural gas consumption for electricity production has been recorded due to a lack of production from hydro potentials due to extremely poor hydrological conditions in some of the EU states. Generally, such declining trends in the production of electricity from conventional power plants are directly related to the very strong expansion of the production of electricity from renewable sources, primarily from wind, sun and biomass.

3.2 Trends of Electricity Production from Renewable Sources in the EU

The fact that in 2017, for the first time in the EU history, more electricity was produced from renewable sources (wind, sun, and bio mass) than from fossil fuels, shows that there is a fantastic ongoing progress in the use of renewable sources for the production of electricity, and that the EU is on the desired path of reducing the negative impacts like global warming and climate change. This progress is best seen in a direct comparison of renewable energy and fossil fuels displayed in Figure 10.

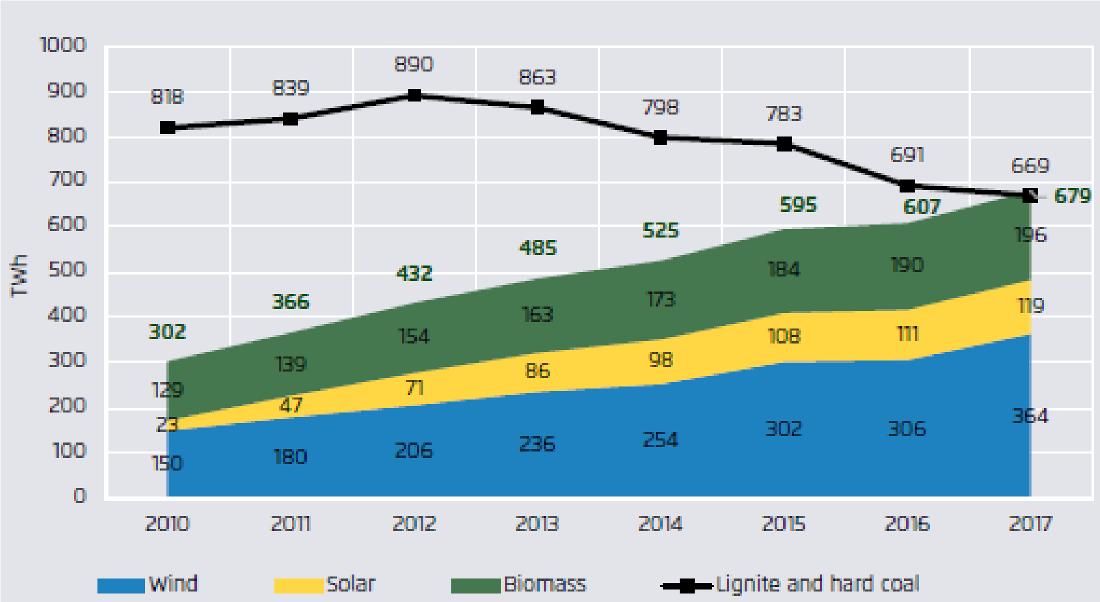

Figure 10. Renewables versus Coal Electricity Production in the EU from 2010 to 2017. This figure shows the EU trends in electricity production coming from renewable sources of wind, solar and biomass on one side, and electricity production from coal on the other, in the period from 2010 to 2017. Adapted from "The European Power Sector in 2017. State of Affairs and Review of Current Developments", by Agora Energiewende and Sandbag, 2018, p. 13, retrieved from https://www.agora-energiewende.de/fileadmin2/Projekte/2018/EU_Jahresrueckblick_2017/Agora_EU-report-2017_WEB.pdf

Figure 10 shows that, in 2017, electricity produced from renewable energies of wind, sun and biomass was in total 679 TWh, which was approximately 1.5% more than the 669 TWh produced by hard coal and lignite. If we break the renewables down into wind, sun and biomass, it is clear that, during the whole seven year period, wind has had the biggest share, followed by biomass and sun. All three sources have recorded a steady and continuous growth in electricity production.

3.3 Trends of Change in the Structure of Electricity Production in the EU

The adopted policies of the 28 EU states in the fight against climate change and global warming of the planet have had a dominant influence on the radical shift in the choice of primary fuels for the production of electricity. If we add to that, the problems and risks of potential incidents and consequences in the production of electricity in nuclear power plants, problems of nuclear waste storage and the very high costs of decommissioning the nuclear power plants, the shift from fossil fuels towards renewable energy in electricity production is quite clear. According to some optimistic forecasts, by 2050, the production of electricity from power plants based on fossil fuels could be completely replaced by renewables. Whether this forecast is yet too optimistic or unrealistic, remains to be seen. But what can be seen from Figure 11, since 1990 up until now, is that there has been an obvious change in the structure of electricity production in the EU, in favor of renewables.

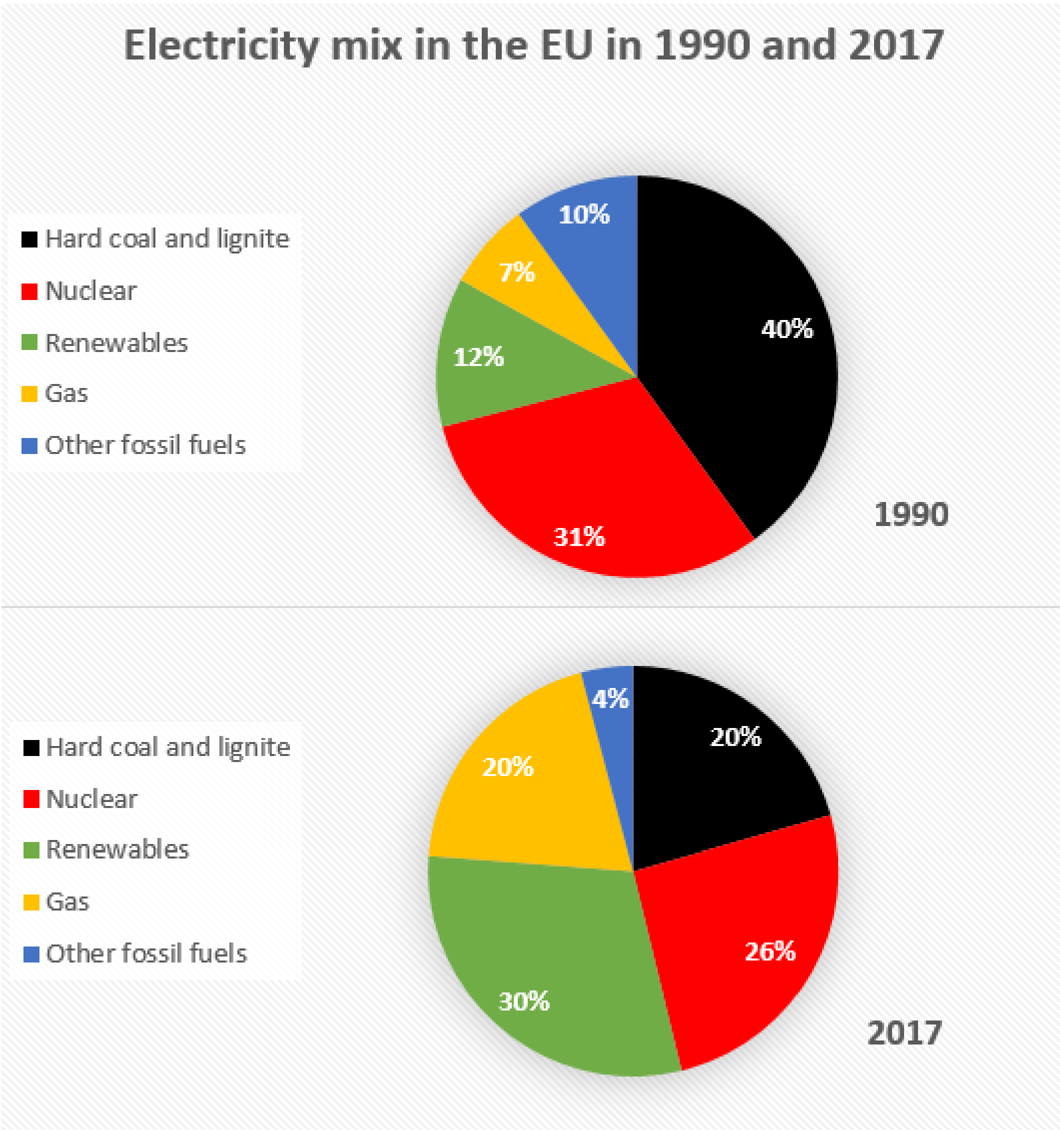

Figure 11. Electricity Production Mix in the EU in 1990 and 2017.

This figure shows the change in percentage share of different energy sources in total electricity production in 28 EU member states in years 1990 and 2017. Data chart for the year 1990 adapted and modified from “Institutional Change and Environment: Lessons from the European Emission Trading System”, by Fernandez, Y. F., Lopez, M. A. F., Hernandez, D. G. and Blanco, B. O., 2018, *Energies, 11* (4)*, 706*, p. 9, doi: 10.3390/en 11040706 . Data chart for the year 2017 adapted and modified from "The European Power Sector in 2017. State of Affairs and Review of Current Developments", by Agora Energiewende and Sandbag, 2018, p. 7, retrieved from https://www.agora-energiewende.de/ fileadmin2/Projekte/2018/EU_Jahresrueckblick_2017/Agora_EU-report-2017_WEB.pdf

By comparing shares of individual energy sources in total electricity production in 1990 and 2017, there are clearly visible declining trends in the use of fossil fuels in electricity generation. The share of coal as the primary fuel was cut in half over the course of less than 30 years, falling from 40% in 1990 to just 20% in 2017. Nuclear energy and other fossil fuels recorded a declining trend as well, falling from 31 and 10% in 1990 to 26 and 4% in 2017, respectively. Contrary to the aforementioned trends, the electricity generation from the so-called green technologies, i.e. from renewable energy sources recorded a strong growth, rising from 12% in 1990 to 30% in 2017, and renewables became the energy source with the biggest share in the total electricity production mix. Interestingly, the percentage share of gas, as a non-renewable energy source, increased in electricity production from 7% in 1990 to 20% in 2017, which indicates that this energy source will still play a significant role in the electricity production for a long time in the future. The reasons behind this trend can be found in a significant amount of world reserves of natural gas and a relatively well-built transport infrastructure, as well as due to planned significant investments in new gas transportation routes.

3.4 Cost Structure of Electricity Production per Different Technologies

The costs of electricity production are one of the key factors for assessing the cost-effectiveness of investments in the construction of power plants. The cost structure of production of electricity in power plants is diverse for different technologies. In addition to the different costs of electricity production from various technologies, there are some specific factors related to a particular technology that furthermore influence the profitability and a decision to invest in such technology, i.e. the type of power plant. For example, as shown in Figure 12, the deviation of the actual number of operating hours of a power plant in relation to the projected annual number (usually 8,000 hours/year) can significantly affect the increase in the costs of electricity production. Variations of such specific factors can have a significant impact on the height of electricity production costs.

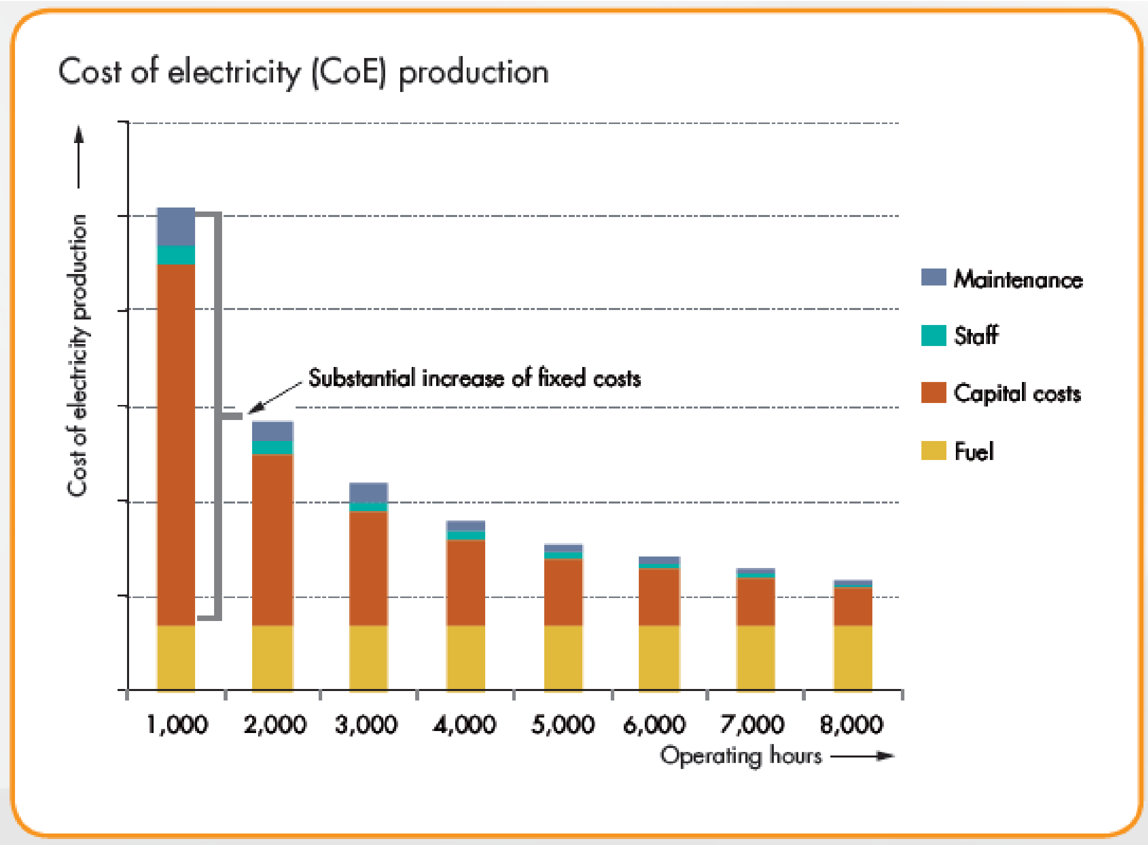

Figure 12. Dependence of the Electricity Production Costs on the Number of Operating Hours of a Power Plant.

This figure shows how costs of electricity production react on the change in the number of operating hours of an average power plant. Adapted from "Facts and Figures: Electricity Generation 2015/2016", by VGB Powertech, Christensen et al. (Ed.), 2015, p. 6, retrieved from https://www.vgb.org/en/data_powergeneration.html?dfid=87612

From Figure 12, it can be clearly seen that the reduction in operating hours of a power plant significantly increases the costs, as costs of capital, costs of staff and O&M costs significantly rise. In order to avoid the increase in these costs, a power plant has to operate with a projected or at least approximately projected number of operating hours.

In order to be able to compare the costs of electricity production from different technologies, unique principles and models have been established, which enable calculation and comparison of production costs from different technologies. Typically, for the sake of simpler analysis and comparability of the results of the analysis, the costs of electricity production are most often observed through costs of fuel, O&M costs, cost of capital, cost of staff, etc.

The costs of electricity production on the European continent are usually expressed in EUR/kWh (EUR per kilowatt hour) or EUR/MWh (EUR per megawatt hour) unit. The most frequently used economic indicator for comparing the costs of electricity production from different technologies is the already mentioned LCOE. However, LCOE is certainly not the perfect measurement tool, because often it does not take into account some other important factors such as: costs of CO_2 emissions, transmission costs, costs of integration to network associated with renewables, depreciation costs, taxes, costs to the local community for the purpose of preserving the environment, decommissioning costs, the impact of the regulation of electricity prices (incentive systems for renewable energy sources), other external costs, etc.

In Table 8, we can see the structure and range of the major costs of electricity production from various technologies that include fixed and variable costs.

Table 8

Typical Capital and Operating Costs for Power Plants per Different Technologies

Technology	Capital costs	Operating costs
	(EUR / kW)	(EUR / kWh)
Pulverised-coal combustion	426-852	0.017-0.034
Natural gas combustion	341-681	0.034-0.085
Wind turbine (includes offshore wind)	1,021.8-4,257.6	< 0.008
Nuclear	1,021.8-4,257.6	0.017-0.043
Photovoltaic solar	> 3,831.3	< 0.008
Hydroelectric	1,021.8-4,257.6	< 0.008

Note. Adapted and modified from “Operating Ratio and Cost of Coal Power Generation”, by Nalbandian-Sugden, H., 2016, p. 33, London, UK. Copyright 2016 by IEA Clean Coal Centre.

Observing the data in Table 8, it is obvious that the structure and the amount of costs differ between conventional technologies and technologies related to renewable energy. Apart from nuclear power plants, the capital costs of all other conventional power plants (coal- and gas-combustion) are much lower than those of power plants based on renewable energy sources (wind, photovoltaic, hydro) which usually requires a huge initial investment. However, on the other hand, the advantage of renewables is in the operating costs which are significantly lower than those of conventional power plants.

Concerning the type of costs, if we observe only capital costs, we can see that, for some technologies, there is a relatively large range of capital costs. The capital costs of building power plants are fixed costs that can vary significantly across individual countries of the EU and the region of Southeast Europe. Costs of land, costs of technologies for environmental protection, costs of obtaining various permits and taxes are all important factors in deciding in which technology regarding the electricity production to invest in. The diversity of these costs is certainly contributing to the relatively high range of capital costs shown in Table 8.

The total operating costs are variable because they are directly related to the quantities of electricity produced, which can vary out of many reasons, for example, in relation to the projected size of a plant, especially typical for power plants based on the energy of sun and wind. There are also many other factors that influence the operating costs. For example, in case of coal-fired power plants, due to the changing market prices of coal and changing costs of its transportation and storage, the impact of variations in these costs may be dominant or even decisive for the economic efficiency of electricity production in such power plants.

In each individual case, before any decision on investing in a certain type of technology the feasibility study should include the calculation of the so called "marginal cost" which in fact represents the total cost required for the production of 1 kWh of electricity.

3.5 Levelized Cost of Energy for Conventional, Photovoltaic and Wind Power Plants

LCOE has enabled a simplified calculation and comparison of the costs of electricity production per different technologies. Models have been created which, on the basis of the official statistical data, enable the calculation and comparison of the costs of electricity production from different technologies over the period of their lifetime. The essence, structure and the calculation procedure of the LCOE will be presented and explained in Chapter 4 of this thesis. In this chapter, the aim is to present the ranges of the LCOE costs for conventional coal-fired power plants, PV and wind power plants in order to create a solid basis for the later comparison of the achieved results of this research.

VGB PowerTech (2015), the international technical association for generation and storage of power and heat from Essen, Germany, published in its annual report a calculation of LCOE for various electricity production technologies in the function of fixed and variable costs (p. 10).

Table 9 shows the input data and the results of the calculation of minimum and maximum LCOE values for individual technologies.

Table 9

Calculation of LCOE per Technology in 2014

Min LCOE calculation

Technology	Investment cost (€/kW)		Discount rate (%)		Lifetime (Year)	O&M (€/kW/a)		Fuel costs (€/MWh)		Carbon price (€/tCO_2)		Electrical efficiency		Carbon factor (tCO_2/MWh)	Full-load hours (h)		LCOE (€ct/kWh)	
	Min	**Max**	**Min**	**Max**		**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**		**Min**	**Max**	**Min**	**Max**
Coal	1,200	1,700	4	7	40	32	39	7	11	5	10	44	46	0.339	2,000	4,500	4.0	11.6
Lignite	1,350	1,800	4	7	40	35	43	4	6	5	10	41	43	0.404	3,000	7,000	2.9	8.4
Gas CCGT	550	800	4	7	30	19	23	19	28	5	10	59	61	0.202	750	2,500	5.3	16.8
Gas OCGT	400	720	4	7	30	14	17	19	28	5	10	39	44	0.202	500	750	9.5	22.7
Nuclear	3,000	5,000	4	7	60	36	44	6	9	-	-	32	37	-	7,000	8,000	3.6	8.4
Hydro run of river	2,300	4,500	4	7	100	25	50	-	-	-	-	-	-	-	3,400	5,500	2.2	10.8
Wind onshore	1,000	1,800	4	7	25	30	50	-	-	-	-	-	-	-	1,800	3,200	2.9	11.4
Wind offshore	2,800	4,500	4	7	25	100	120	-	-	-	-	-	-	-	3,000	4,200	6.7	16.9
PV ground mounted	900	1,600	4	7	25	13	25	-	-	-	-	-	-	-	900	2,000	3.5	18.0

Max LCOE calculation

Note. CCGT = Combined Cycle Gas Turbine; OCGT = Open Cycle Gas Turbine; a = annual; tCO_2 = ton of CO_2 ; €ct = Euro cent. Adapted from "Levelized Cost of Electricity: LCOE 2015", by VGB PowerTech, 2015, p. 10, Essen, DE: VGB PowerTech Service GmbH.

Table 9 presents a complex method of calculating the LCOE that takes into account the investment cost, discount rate, expected lifetime of a power plant, O&M costs, fuel and CO_2 costs (when there are any) and full-load hours. Based on the results of the calculation of the LCOE from Table 9, an analysis conducted by VGB PowerTech in 2015, Figure 13 provides a graphical representation of the typical LCOE range for different technologies.

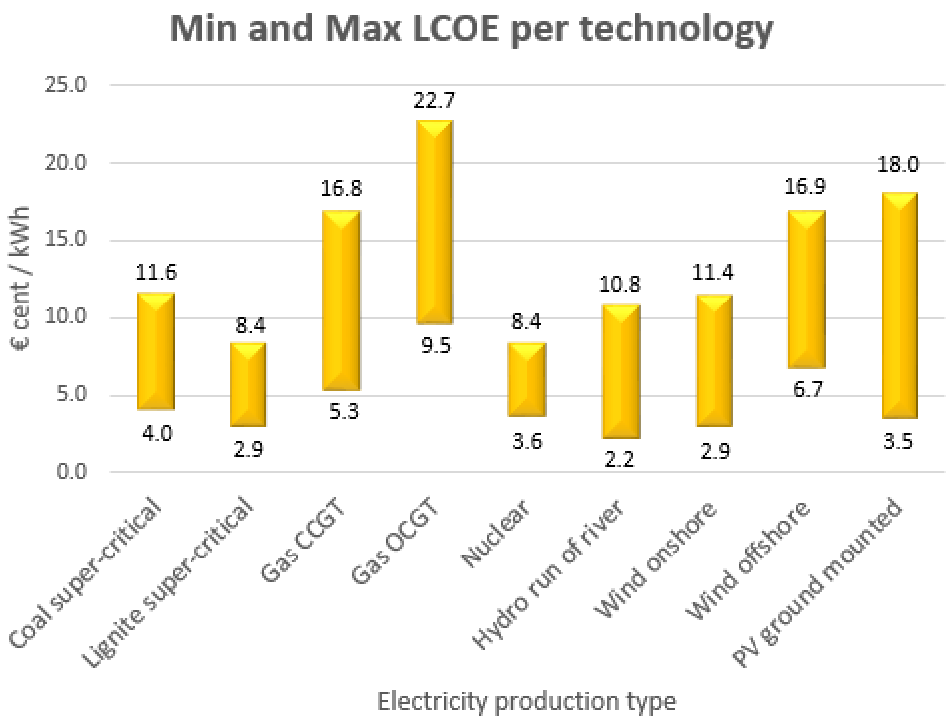

Figure 13. LCOE Range per Technology in 2014.

This figure illustrates how different technologies for electricity production compare between each other in terms of their respective minimum and maximum LCOE values, calculated on the basis of data from 2014. Adapted from “Levelised Cost of Electricity: LCOE 2015”, by VGB PowerTech, 2015, p. 11, Essen, DE: VGB PowerTech Service GmbH.

If we compare the calculated LCOE values of electricity production from coal on the one side and wind and sun on the other, we can see that the electricity produced by onshore wind plants has become very competitive to coal-fired production, in terms of minimum and maximum LCOE, importantly while maintaining all its comparative advantages, i.e. no fuel costs and minimal environmental impact. Regarding the sun energy, if we take into consideration the ever-growing number of the PV power plants in the world, as well as the constantly decreasing costs of the main components of the equipment (solar panels and inverters), it is reasonable to assume that in terms of competitiveness, PV power plants will very quickly become a serious competitor to the electricity production from coal. However, production from renewable sources of wind and sun does have its deficiencies. These are mainly the higher production volatility and a heavy dependence on the abundance of wind and sun. As a consequence, the need for the construction of some kind of storage capacities for the produced energy has emerged. To some extent, these reasons have slowed down the process of achieving the competitiveness of the electricity produced by using coal as the energy source, but, without a doubt, in terms of just LCOE, renewables will eventually become more profitable to invest in.

4. Theoretical Foundations and Tools for Conducting the Profitability Analysis of Power Plants

When it comes to conducting the profitability analysis of a power plant, besides the calculation of the standard measures like Net Present Value (NPV), Internal Rate of Return (IRR), Equity payback time and Benefit-cost ratio, one of the crucial tasks is estimating the costs of electricity production. Calculating the costs of electricity production is generally a complex process. Electricity production costs are determined as a function of a set of parameters that can be fixed or variable, short-term or long-term, predictable or unpredictable. Different technologies have different cost structures, they are in different ways subject to changes in the most influential factors such as, for example, the usage period of the installed power, fuel and emissions costs during the lifetime of thermal power plants, investment costs, costs of disposing of nuclear waste, decommissioning costs after the expiration of a lifetime of a power plant, and many others.

These specificities have led to the need to find models and tools that will allow a transparent comparison of the price of one produced kilowatt hour (expressed in EUR/kWh or EUR/MWh) among power plants based on different technologies in order to be able to assess the profitability of investments in electricity production from different technologies.

The broadest application in the practice of determining and comparing the costs of electricity production from different technologies that has been found, is mentioned in the previous chapter: LCOE.

Foster, Wagner and Bratanova (2014) made a comparative analysis of several known LCOE models designed for the needs of national governments with an emphasis on the analysis of the impact of capital costs as one of the most important factors for selecting technology for investment in electricity production on one side, and the influence of different discount rates in individual models and individual countries on the other. The authors' conclusion was, that, despite the diversity of the LCOE models on an international level and within single countries as well, LCOE models are very reliable in determining projections of electricity production costs and should be quite sufficient for making investment decisions (pp. 2 & 23).

This chapter will present all the models and tools used for the profitability analysis in the case study in Chapter 5, as well as the procedure and equations used for the calculations of the key measures. Section 4.1 will elaborate the LCOE and its calculation method, while sections 4.2 and 4.3 the NPV and IRR respectively. In addition there were two software tools used, which enabled faster, automatic calculations of some measures. In this matter, Section 4.4 will introduce and present the PVGIS software, a software tool specialized for making the electricity production simulations for the PV power plants, while Section 4.5 provides a short explanation of the Fractal software, a tool used as the automatic helping hand in some financial calculations.

4.1 Levelized Cost of Energy

In general, LCOE is a tool designed to economically estimate the average total cost of building and operating an energy production plant during its lifetime, discounted to the present value. By calculating LCOE, it should be possible to compare the production of electricity from different technologies and on the basis of this comparison, draw conclusions about the cost-effectiveness of investments in individual power generation plants.

In the literature, the most commonly used basic formula for calculating LCOE is displayed under the label *Equation 1* (Ebenhoch, Matha, Marathe, Munoz & Molins, 2015, p. 109).

$$\mathbf{LCOE} = \frac{I_0 + \sum_{t=1}^{n} \frac{A_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}} \tag{1}$$

I_0 = Initial investment cost (capital expenditure)
A_t = Annual O&M costs in year (t)
F_t = Annual fuel costs in year (t)
E_t = Annual electricity produced in year (t)
r = Discount rate
n = The (expected) lifetime of the power system expressed in years
t = Year of lifetime

In addition to the above-mentioned *Equation 1*, which is the most frequently used form of the LCOE calculation formula, the basic formula can also be extended by adding other specific costs of particular technologies (e.g. CO_2 emissions, plant decommissioning costs, etc.), resulting in the more precisely determined average total electricity production costs. The LCOE calculations in subsequent Chapter 5 were made on the basis of *Equation 1*.

4.2 Net Present Value

The Net Present Value (NPV) is essentially the sum of present values of cash inflows and present values of cash outflows over a period of time. Prior to making a decision on investing in electricity production, an investment profitability of the future project is carried out in order to determine whether potentially generated returns are at the level of the designated values. NPV proved to be a useful model and as such is often used in a comprehensive assessment of the profitability of future investments.

In the calculation of NPV in practice, the following equation is often used (Jory, Be namraoui, Boojihawon & Madichie, 2016, p. 87):

$$\mathbf{NPV} = CF_0 + \sum_{t=1}^{\mathrm{T}} \frac{CF_t}{(1+r)^t} \tag{2}$$

CF_0 = Initial investment

CF_t = Project's cash flows in year t

r = Discount rate

t = Year

The result of *Equation 2* can be either positive or a negative value. The first part of the equation, i.e. the initial investment marked as CF_0 is understandably negative, so the result of the equation will only be positive if the sum of the future annual discounted cash flows is greater than the amount of the initial investment. For projects (investments) in which NPV is positive, it can be concluded that the project (investment) is profitable because the income generated by this project (investment) exceeded the expected costs expressed in the net present monetary unit. Otherwise, if the result of the NPV calculation is negative, the project (investment) is not profitable and investments in such projects (investments) would result in a net loss.

4.3 Internal Rate of Return

The Internal Rate of Return (IRR) is another important tool in assessing the profitability of a potential investment. It is usually an important factor in investment decisions who's meaning gains in importance when it is used in combination with the NPV method.

IRR is basically a discount rate at which the NPV of a project with all its positive and negative cash flows is equal to zero. But in order to find a practical meaning of the IRR for one project, it has to be compared to the cost of capital of that project. According to El-Tahir and El-Otaibi (2014) "an investment is considered acceptable if its internal rate of return is greater than an established minimum acceptable rate of return or cost of capital" (p. 217). In other words, the project is profitable only if IRR is higher than the cost of capital, and the higher the IRR, the higher is the potential profitability of the project. When comparing two or more projects, when solely deciding on the basis of IRR, the one with the higher IRR would always be preferred over the one with lower.

So in order to calculate the IRR, we will use the same equation as we used for the NPV, i.e. *Equation 2* from Section 4.2 and set it equal to zero. *Equation 3* now sets the ground for calculating the IRR.

$$\mathbf{NPV} = CF_0 + \sum_{t=1}^{T} \frac{CF_t}{(1+r)^t} = 0 \qquad (3)$$

CF_0 = Initial investment

CF_t = Project's cash flows in year t

r = IRR

t = Year

Equation 3 shows that we are looking for the discount rate r at which the NPV equation is equal to zero. In this case, the discount rate r is actually the IRR and unlike NPV which is expressed in a monetary unit, the IRR is expressed in percentages.

In combination with the other profitability measures, like NPV for example, the IRR can prove to be a reliable measure in the profitability analysis of an investment.

4.4 PVGIS Software

As stated earlier in the paper, PVGIS is an acronym of Photovoltaic Geographic Information System. It is a free online calculator with a purpose of estimating the production of electricity in the PV systems. With this calculator, it is possible to estimate the daily, monthly and total annual production of PV systems in Europe, Asia and Africa. As a geographical basis and source of geographical maps, the calculator uses commonly used and widespread Google maps.

PVGIS is the product of the European Commission Joint Research Center and currently the model PVGIS 4 is in the use, while PVGIS 5 is in the testing phase (European Commission Joint Research Center, 2017a, para. 1).

PVGIS calculator mainly uses databases created and based on long-term measurements of solar radiation on ground stations throughout the Europe, data related to solar radiation parameters collected by satellites, as well as the average annual air temperatures and other relevant meteorological parameters.

Using the PVGIS calculator, it is possible to estimate the solar radiation at a selected point defined by the geographical coordinates and the expected production of electricity at the daily, monthly and annual levels with quite high precision.

In doing so, it is important to note that the PVGIS Calculator takes into account a series of influential parameters such as angles of inclination of the PV panels in relation to the horizontal plane, the angle of azimuth, as well as the impact of losses of PV panels and PV system as a whole. All the parameters and values can be set in the user interface of the software, shown in Figure 14.

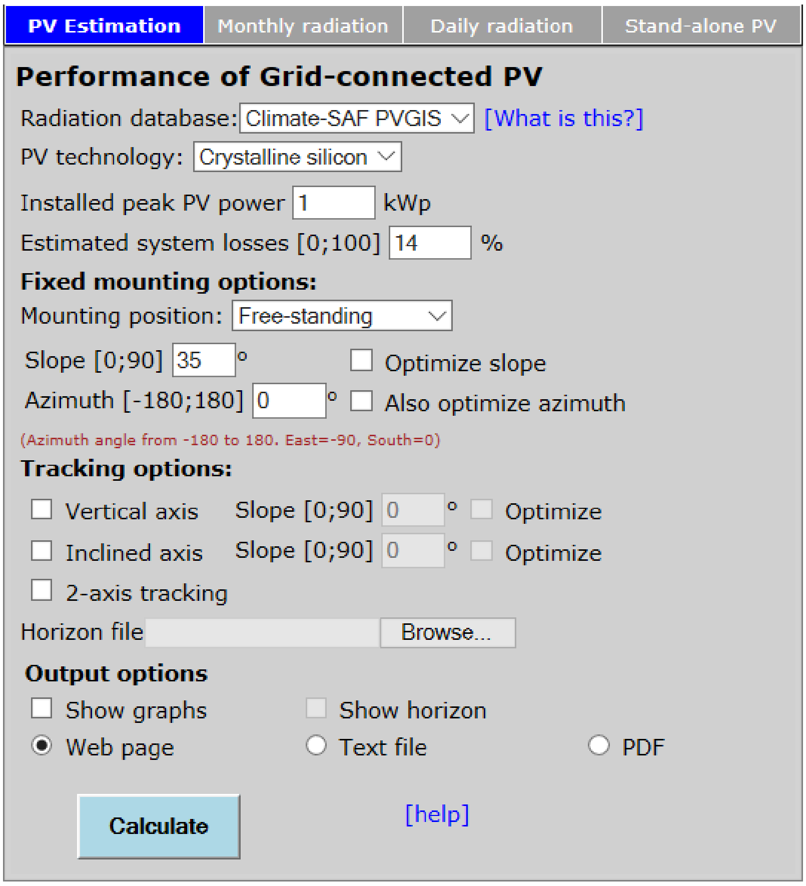

Figure 14. User Interface of the PVGIS Calculator.

This figure shows an example of how the user interface of the PVGIS software looks like. The calculated values of electricity production in a PV plant are an estimation based on the input parameters entered by a user. Adapted from “Photovoltaic Geographical Information System - Interactive Maps”, by European Commission Joint Research Center, 2018, retrieved from http://re.jrc.ec.europa.eu/pvgis/apps4/pvest.php#

In addition to these features, for a number of states, there are maps of solar energy potentials with global radiation values on the horizontal plane. This factor is very important when choosing to invest in the PV power plants, because of the high volatility of daily resources in the electricity production. Figure 15 shows one such map, in this case for BiH.

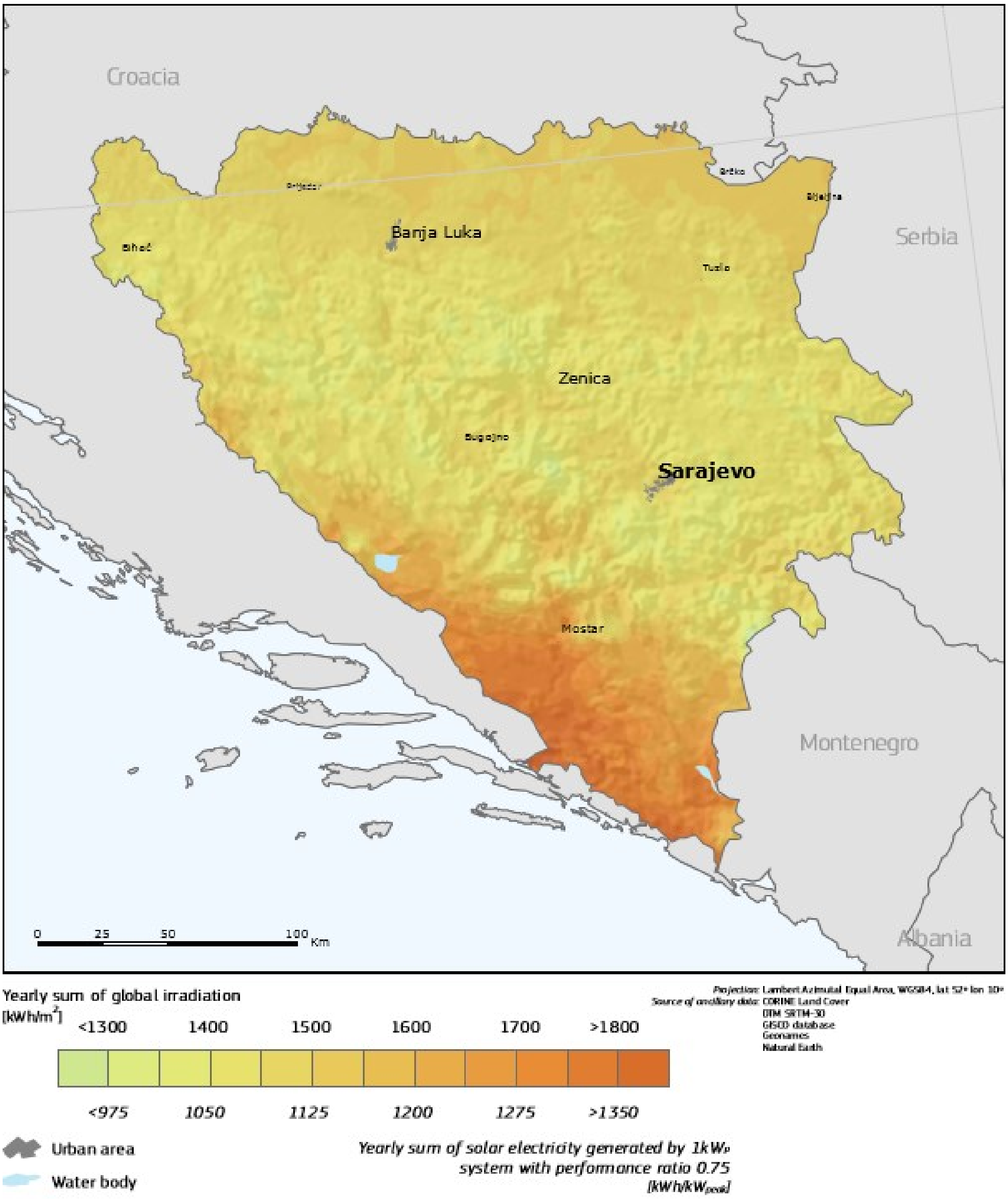

Figure 15. Global Irradiation and Solar Electricity Potential in BiH by Optimally Inclined PV Modules.

This figure shows the map of BiH in terms of estimated yearly solar electricity potential throughout the country. Adapted from “Country and Regional Maps”, by European Commission Joint Research Center, 2017b, Available from http://re.jrc.ec.europa.eu/pvg_download/map_index.html#!

The map from Figure 15 shows that the value of total annual solar radiation in BiH ranges from 1300 kWh/m^2 in the northern areas to 1800 kWh/m^2 in the southern areas of the country. Unfortunately, such values of total annual solar radiation, which for example are higher than the total solar radiation in Germany for about 30-40%, are not sufficiently exploited for the purposes of electricity production. The reason for this lies, in the first place, in the poverty of the energy sector and the lack of financial resources for investing in the production of electricity from renewable sources in general. If to these facts we add the uncomplete legislation and system of incentives for the production of electricity from renewable sources, we gain a clear picture of obstacles to the use of renewable sources for electricity production in BiH.

4.5 Fractal Software

Company "Fractal" Split (Croatia) has developed a model for calculating the feasibility of building PV systems for the production of electricity from solar energy. Based on interconnected Excel spreadsheets, the model, in a very simplified but sufficiently accurate way, answers the question of profitability of investment in a PV power plant, while still in the stage of considering the possible investment.

Excel spreadsheet contains 5 worksheets: Basic Data, Revenue, Investment Costs, Operating Costs, and Financial Analysis (Jerkic, 2011, para. 5). By inputting the basic technical data of the future PV power plant, as well as other data such as data on financing and taxes, it is possible to calculate the revenues during the lifetime of a PV power plant, the costs of construction and operating costs and ultimately, through the financial analysis, determine the IRR, NPV, equity payback time and cost benefit ratio. Although the software is centered on the calculations related to the PV power plants, it can also be used as a helping tool for the automatization of the calculations related to other types of power plants and businesses as well.

Figure 16 shows the layout and structure of the first worksheet for entering the basic data about the planned project. The rest of the model contains the other four, above mentioned worksheets that are subsequently calculated.

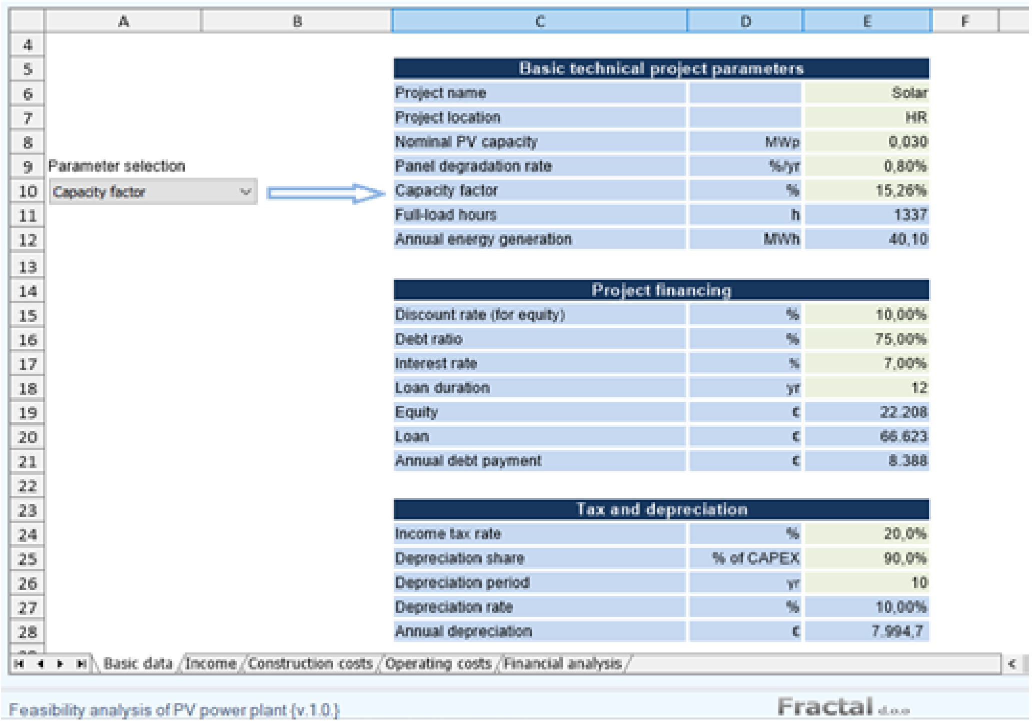

Figure 16. Example of the Fractal Software Interface.

This figure provides an example of how the Fractal's excel spreadsheet model looks like, i.e. the first worksheet intended for entering the basic data as the basis for later calculations. The figure is created in Fractal Software by the author of this paper.

On the basis of the entered basic data, calculation of the total income, O&M costs of the PV system during its lifetime, and basic financial data (cost of capital, interest and taxes), the program generates a graphical and tabular presentation of the equity cash flow, as well as profitability indicators, which are often sufficient to assess the feasibility of investing in the construction of primary a PV power plant, but with some modifications of the other types of power plants as well. Fractal software is suitable for analyzing the profitability of both small and large businesses.

5. Case Study: Economic and Financial Profitability of Electricity Production in Photovoltaic, Wind and Coal-Fired Power Plants

In Chapter 5, the focus of the research was conducting the analysis of the feasibility of construction and the economic and financial viability of electricity production in coal-fired thermal power plants and power plants based on renewable sources of sun and wind in BiH.

The goal was to make a basis for finding the answer on the ultimate question of this research paper, i.e. in which direction to develop the production of electricity and what would be the optimal mix between the production from conventional and production from renewable energy sources in BiH and developing countries, and thereby ensure sustainable economic growth and development while meeting the commitments in the fight to halt climate change and protect the environment, as well as to encourage production from renewable energy sources. By no means is this an easy task if we know that BiH still receives the bulk of its electricity from conventional sources, primarily from coal. At the same time, one of the main issues is the status of the coal-fired thermal power plants that are currently at or near the end of their lifespan. BiH does not have enough investment potential for the introduction of new technologies and rehabilitation of existing thermal power plants whose lifespan is not near the end, but which do not meet the limit values of emission from large furnaces.

The case study consisted of the three main parts. Section 5.1 is the case study and the profitability analysis of the first PV power plant in BiH, called PV power plant “Kalesija”. Section 5.2 is the case study of “Mesihovina”, the first wind farm in BiH, and section 5.3 the case study of “Block 7 Tuzla”, which is actually the planned investment in additional production unit of the already existing coal-fired “Thermal Power Plant Tuzla”, located in Tuzla, the third largest city in BiH and the economic and industrial center of the northeastern region of the country.

5.1 Profitability Analysis of “Kalesija”, the First Photovoltaic Power Plant in Bosnia and Herzegovina

The first PV power plant in Bosnia and Herzegovina, with the power of 120 kW was built and put into operation in 2012 in the municipality of Kalesija (the entity of FBiH). The investor is the local company "*Eko Energija* [Eco Energy]” from Kalesija. PV power plant “Kalesija” is installed on the roof of the local sports hall in Kalesija.

In order to reduce losses in electrical installations, inverters (total of 8 pieces) are located beneath the roof itself, close to the PV panels. According to Regulatory Commission for Energy in Federation of Bosnia and Herzegovina (2011), PV Power plant “Kalesija, with the installed capacity of 120 kW on the alternating current side, is designed for an annual production of 130.3 MWh of electricity (p. 6).

Section 5.1.1 will display the key economic and technical parameters of the PV power plant “Kalesija”, Section 5.1.2 shows the data resulting from the simulations of electricity production, using PVGIS software. After the simulation, Section 5.1.3 provides a direct comparison between the projected and the actual amounts of produced electricity. The analysis of the PV power plant “Kalesija” is rounded up with Section 5.1.4 which presents a comprehensive financial analysis, including the calculations of the profitability measures on the basis of models and equations presented in Chapter 4.

5.1.1 Economic and Technical Indicators

Regulatory Commission for Energy in Federation of Bosnia and Herzegovina has issued to the company "Eco Energy" a license for performing electricity production activities. An integral part of this license is the description and the list of the technical and energy parameters of the PV power plant “Kalesija”. Table 10 shows the shortened list with the most important technical and energy indicators.

Table 10

Basic Technical and Energy Parameters of the PV Power Plant "Kalesija"

Parameter	Unit	Value
Name		"*Sportska hala Kalesija* [Sports Hall Kalesija]"
Owner		"Eco Energy" Ltd. Kalesija
Location		Roof of a sports hall in municipality of Kalesija
Northern geographic latitude		44°26'37"
Eastern geographic longitude		18°54'29"
Type of renewable energy source used		Solar energy
Total annual irradiation	(kWh/m^2)	1,510
Method of implementation		Roof design
Number of objects on which PV panels are installed	(Number)	1
Total area of roof surface on which PV panels are installed	(m^2)	1,700
Total number of PV panels	(Number)	504
Total surface of PV panels	(m^2)	838
Unit power of a PV panel	(Wp)(3)	240
Total installed capacity – DC(1)	(kWp)(4)	123
Total installed capacity – AC(2)	(kW)	120
Estimated annual production of electricity	(MWh)	130.3
Projected annual operating time	(h)	1,250
Amount of reduction in CO_2 emissions	(kg/year)	157,826
Total nominal degree of utilization	(%)	10.2
Projected amount of energy obtained from 1 kWp	(kWh/year)	1,061

Note. (1)DC – Direct Current, (2)AC – Alternating Current; (3)Wp – watt peak (4)kWp – kilowatt peak. Adapted and modified from "*Prethodna dozvola za izgradnju proizvodnog objekta solarne fotonaponske elektrane 'Sportska hala Kalesija' za privredni subjekt „Eko Energija" d.o.o. Kalesija, općina Kalesija* [Previous Permit for the Construction of the Production Facility of Solar Photovoltaic Power Plant "Sports Hall Kalesija" for the Undertaking "Eco Energy" Ltd. Kalesija, Municipality of Kalesija]”, by Regulatory Commission for Energy in Federation of Bosnia and Herzegovina, 2011, p. 6, retrieved from http://www.ferk.ba/_ba/images/stories/2011/2212-dz-pdi-eko-energija-bs.pdf

Technical data listed in Table 10 are crucial for making the analysis of the feasibility of construction of the PV power plant “Kalesija” and for the calculation of its key profitability indicators.

5.1.2 Software Simulation of Electricity Production

PVGIS software described in Chapter 4 enabled a simulation of electricity production in the PV power plant “Kalesija”. The PV power plant “Kalesija” is connected to the electricity distribution network and all of the produced electricity is injected into the distribution network. Since geographical location is extremely important when it comes to PV power plants because of their high dependence on the abundance of sun, PVGIS tool enabled the simulation for the exact geographical location of the PV power plant “Kalesija” listed in Table 10.

Geographical location and all the other data that were entered as the basis for the simulation were following:

- Location: 44°26'37" North, 18°54'29" East, 349 m a.s.l.[2] elevation;
- Solar radiation database used: PVGIS - Classic;
- Nominal power of the PV system: 123.0 kW (crystalline silicon);
- Estimated losses due to temperature and low irradiance: 13.8% (using local ambient temperature);
- Estimated loss due to angular reflectance effects: 3.0%;
- Other losses (cables, inverter etc.): 16.0%;
- Combined PV system losses: 29.8%.

Table 11 shows the results of the simulation of the production of the PV power plant “Kalesija” using the PVGIS software and on the basis of the above mentioned input data.

[2] m a.s.l. – meters above sea level

Table 11

PVGIS Software Simulation of Electricity Production in PV Power Plant "Kalesija"

Fixed system[1]: inclination=32°, orientation=0°				
Month	**Average daily electricity production**	**Average monthly electricity production**	**Average daily sum of global irradiation per m^2 received by the modules**	**Average monthly sum of global irradiation per m^2 received by the modules**
	(kWh)	(kWh)	(kWh/m^2)	(kWh/m^2)
Jan	196.00	6,070	2.09	64.70
Feb	262.00	7,320	2.82	78.90
Mar	350.00	10,800	3.94	122.00
Apr	409.00	12,300	4.76	143.00
May	463.00	14,400	5.48	170.00
Jun	467.00	14,000	5.62	168.00
Jul	507.00	15,700	6.18	192.00
Aug	478.00	14,800	5.84	181.00
Sep	429.00	12,900	5.06	152.00
Oct	331.00	10,300	3.77	117.00
Nov	209.00	6,280	2.30	69.00
Dec	171.00	5,320	1.82	56.40
Annual average	356.00	10,800	4.15	126.00
Annual total		**130,000**		**1,510.00**

Note. [1] The PV system of the PV plant "Kalesija" is fixed to the south and at an angle of inclination of 32°. Data from the table are personal calculations conducted in the PVGIS Software.

As we can see from Table 11, the total estimated yearly electricity production for the PV power plant "Kalesija" is 130,000 kWh, i.e. 130 MWh. If we compare this simulated value with the projected 130.3 MWh of annual electricity production of the PV power plant "Kalesija" listed in the obtained license as part of the technical and energy indicators shown in Table 10, we can conclude that the calculations are approximately the same for the given location and set parameters that were included in the simulation. PVGIS Software has proved to be a quite reliable tool in presenting a fairly realistic estimate of the possible production of electricity from a PV power plant.

5.1.3 Comparison of Projected and Actual Produced Electricity

As already mentioned in the introduction of the Section 5.1, PV power plant "Kalesija" started operating in 2012. Thanks to the exceptionally favorable weather conditions, in the first years of operation, the achieved annual electricity production was above the projected 130.3 MWh. Table 12 shows how and in which direction did the actual realized amounts of produced electricity differ from the projected values.

Table 12

Overview of the Projected and Realized Electricity Production in PV Power Plant "Kalesija"

Year	**Projected electricity production with included yearly degradation of PV panels of 0.30%**	**Actual realized electricity production recorded by electricity meter[1]**	**Deviation of actual from planned electricity production**
	(kWh)	(kWh)	(%)
2012	130,300	142,201	1.0913
2013	129,700	151,978	1.1718
2014	129,300	145,792	1.1275
2015	128,900	154,491	1.1985
2016	128,500	127,067	0.9888
2017	128,100	148,724	1.1610
Total	**774,800**	**870,253**	**1.1232**

Note. [1]Data on realized electricity production adapted from "Overview of the produced electricity in PV power plant 'Kalesija' (kwh) [unpublished raw data]", by Eco Energy Ltd., 2018.

From Table 12 we can see that, in the period from the start of operation until the end of 2017, the actual realized electricity produced was above the projected amounts in every year except from 2016. The total realized electricity production for the six year period was 870,253 kWh, which was 12.32% more than the projected value (with annual degradation of the PV panels of 0.30%) in the same period. The reasons for such good results in electricity production were extremely favorable weather conditions during the summer months (except in 2016), well-selected equipment (primarily PV panels and inverters) and operation of the power plant without any significant equipment malfunction.

5.1.4 Financial Analysis

The profitability analysis of the PV power plant “Kalesija” was conducted with the help of Fractal Solar software whose purpose and possibilities were described in Section 4.5 of this paper.

The key assumptions and data used in the analysis of the cost-effectiveness of the construction of the PV power plant “Kalesija” refer to the year 2012, when the power plant was put into operation. Although this PV power plant has been fully operating for more than six years now, the purpose of this paper is the analysis of the investment choice in renewables over conventional power plants, from the standpoint where we need to opt to go in one direction over the other, so we will need to get back to the time prior to the start of the operation of the power plant and analyze how the, then future PV power plant “Kalesija” would stand in a feasibility study.

The financial analysis, based on the official data from 2012 of the relevant institutions in BiH and the EU, included the following five steps:

1) overview of the basic data - basic technical parameters, project financing, depreciation and taxes (Section 5.1.4.1 of this paper);
2) calculation of revenues from electricity sales (in-feed tariffs and duration of the in-feed rates, movements in electricity prices in 2012 and future trends in price during the lifetime of the power plant, as well as the then current exchange rates) (Section 5.1.4.2);
3) overview and estimation of the construction costs, equipment costs and costs of documentation acquisition (Section 5.1.4.3);

4) overview and estimation of O&M costs - periodic costs, rent of the roof of the sports hall, insurance costs and other unexpected expenses (Section 5.1.4.4);
5) calculation of the profitability measures - equity cash flow, financial viability, IRR, NPV, Equity payback time, cost-benefit ratio (Section 5.1.4.5).

5.1.4.1 Basic Data

The feasibility study was done on the basis of the input data shown in Table 13, of which some are calculated by software and some manually entered. The technical parameters refer to the PV panels composed of monocrystalline silicon. Table is divided into 3 main subsections of indicators: basic technical parameters, project financing data and taxes and depreciation.

Table 13

Basic Data Used in Fractal Software Analysis of the Profitability of the PV Power Plant "Kalesija"

Basic technical project parameters		
Component	Unit	Value
Project name		PV power plant "Kalesija"
Project location		BiH
Nominal PV capacity	(MWp)[(1)]	0.123
Panel degradation rate	(% / year)	0.20
Capacity factor	(%)	12.07
Full-load hours	(h)	1,057
Annual energy generation	(MWh)	130.05
Project financing		
Discount rate (for equity)	(%)	10
Debt ratio	(%)	80
Interest rate	(%)	8.50
Loan duration	(year)	9
Equity	(€)	61,123
Loan	(€)	244,490
Annual debt payment	(€)	39,956
Tax and depreciation		
Income tax rate	(%)	10
Depreciation share	(% of CAPEX)[(2)]	90
Depreciation period	(year)	12
Depreciation rate	(%)	8.33
Annual depreciation	(€)	22,921

Note. [(1)]MWp – megawatt peak. [(2)]CAPEX – capital expenditure. Green fields were calculated automatically by the software; white fields were manually calculated and entered in consultation with an expert from the project bearer company.

On the basis of the basic data shown in Table 13, the software calculated a possible annual electricity production of 130.05 MWh. The financing of the project is split between 80% loan with an interest rate of 8.50% and a loan repayment period of 9 years, and 20% of own investor's participation. The result of the calculation is a credit indebtedness of 244,490 €, own participation of 61,123 € and annual loan repayment of 39,956 €. The profit tax rate is 10%, and for the entered data, the software calculated the depreciation rate of 8.33% for a period of 12 years, which is a period of the guaranteed purchase price of electricity.

5.1.4.2 Revenues

In order to calculate the income from the produced electricity, it is necessary to know the amount of produced electricity in kWh and the purchase price of electricity. The product of these two values yields the revenues from the produced electricity. Table 14 shows the input data for the calculation of revenues achieved from the estimated electricity generation in the PV power plant "Kalesija".

Table 14

Input Data Used in Fractal Software for the Calculation of Revenues of the PV Power Plant "Kalesija"

Inflation and lifetime		
Item	Unit	Value
Inflation rate(1)	(%)	2.10
Project lifetime	(year)	25
Electricity price		
Price assumption	-	Manual input
Exchange rate(2)	(BAM/€)	1.95583
Factor for "local component"	-	0.95
Feed-in tariff duration	(year)	12
Feed-in tariff (1st year)(3)	(BAM/kWh)	0.736
Current electricity market price(4)	(BAM/kWh)	0.1226
Electricity price growth rate	(%)	2.40
Feed-in tariff (1st year)	(€/MWh)	376.30
Current electricity market price	(€/MWh)	62.70

Note. Green fields were calculated automatically by the software; white fields were manually calculated and entered in consultation with an expert from the project bearer company. BAM – international abbreviation for Bosnian currency. (1)Inflation rate for year 2012 adapted from "Consumer Price Index in Bosnia and Herzegovina 2012" by Agency for Statistics of Bosnia and Herzegovina, 2013, p. 17, Sarajevo, BA. (2)Exchange rate for March, 2012 adapted from "Currency Exchange", by Central Bank of Bosnia and Herzegovina, 2018, retrieved from: https://www.cbbh.ba/CurrencyExchange/?lang=en (3)(4)Market price for year 2012 adapted from "*Kako izračunati važeću otkupnu cijenu za energiju iz obnovljivih izvora?* [How to Calculate the Valid Market Price for Energy from Renewable Sources?]", by Regulatory Commission for Energy in Federation of Bosnia and Herzegovina, 2018, retrieved from http://www.ferk.ba/_ba/index.php/dozvole/uputstva/141-uputstva/18351-kako-izracunati-vazecu-otkupnu-cijenu-za-energiju-iz-obnovljivih-izvora

In calculating the revenues from generated electricity, annual revenues in the first 12 operating years of the PV power plant “Kalesija” were calculated at the guaranteed purchase price, and from 13th to 25th year of operation, that is, to the end of its lifetime, at the expected reference market price with the assumed electricity price growth rate. Also, the inflation rate of 2.1% in BiH was taken into account, which is the lowest among the countries of West Balkans, to a great extent due to a long-term solid link of the national currency (Bosnian Mark – BAM) to the Euro.

Figure 17 shows the movement of the purchase price of electricity during the 25 year lifetime of the PV power plant “Kalesija”. During the first 12 years of operation, the power plant is in the incentive system and has the right to sell electricity at a guaranteed price of 376.3 €/MWh. From the 13th year of operation until the end of the lifetime, the price at which the electricity is sold starts at 62.7 €/MWh with a projected annual growth of 2.4%.

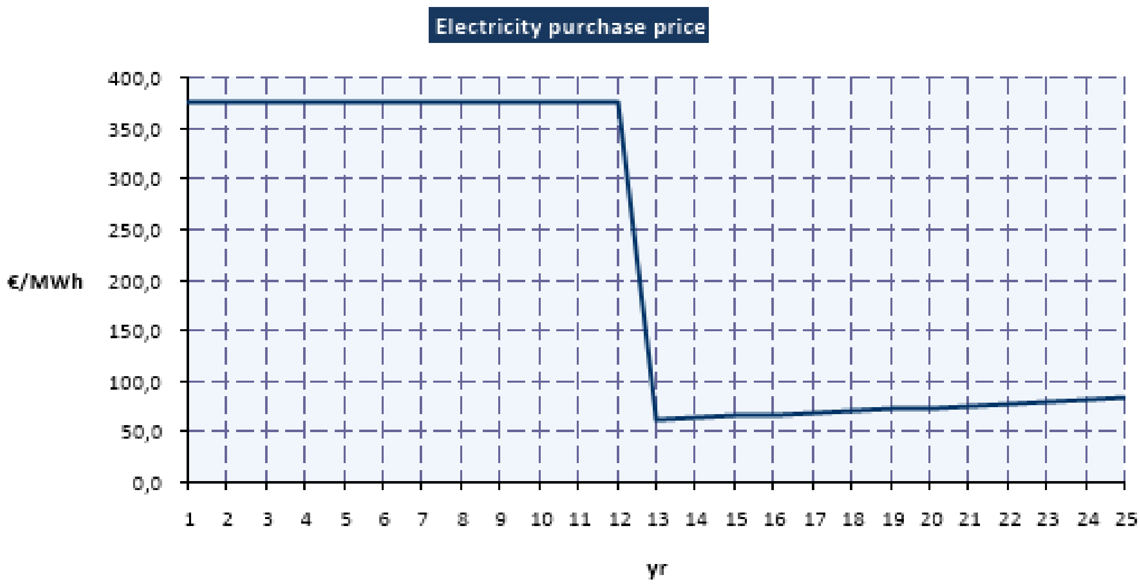

Figure 17. Graphical Presentation of the Movement of the Electricity Purchase Price during the Lifetime of the PV Power Plant “Kalesija”.

This figure shows how the price of electricity, expressed in €/MWh unit, changed over the course of 25 operating years of the PV power plant “Kalesija”. X-axis represents time period expressed in years, and Y-axis represents the price in €/MWh. The figure was created in Fractal Software.

There are several reasons behind the expectation that the market electricity price will annually grow. Generally, trends in electricity consumption indicate that electricity demand in the world will grow primarily thanks to the increase in the planet's population, the increased consumption of heating / air conditioning / ventilation systems, but also due to the increasing number of electric cars in use. This growth in electricity consumption will result in an increase in market prices of electricity. Assuming the annual growth rate of electricity prices on the open electricity market of 2.4%, the initial electricity price of 62.7 €/MWh in the 13th year of operation of the PV power plant "Kalesija", i.e. in the year when the period of sale at the guaranteed price ends, should reach the level of 83.4 €/MWh in the final year of its operation.

The regulator has determined the guaranteed purchase price in such way so that the project is paid off in 12 years, after which the duration of the period at the guaranteed purchase price ends. For example, the duration of incentives in Bosnia and Herzegovina is 12 years, while, in Germany, the incentive system lasts for 20 years. Considering the fact that the reference market price is a lot smaller, the profitability of the PV power plants in BiH after 12 years and until the end of its lifetime is very questionable. The O&M costs grow, while revenues from the sale of produced electricity drop dramatically due to market electricity prices that are much lower than the guaranteed price, while the plant is in the incentive system. Table 15 shows exactly how drastically total annual income falls after the 12th year of operation, i.e. after the end of the electricity sale at the guaranteed price.

Table 15

Electricity Purchase Price, Production and Total Income per Year during the Lifetime of the PV Power Plant "Kalesija"

	Manual input	**Annual energy generation**	**Total income**
Year	(€/MWh)	(MWh)	(€)
1	376.3	130.1	48,939.8
2	376.3	129.7	48,840.6
3	376.3	129.3	48,742.8
4	376.3	128.9	48,644.6
5	376.3	128.5	48,547.0
6	376.3	128.1	48,449.1
7	376.3	127.7	48,351.2
8	376.3	127.3	48,253.4
9	376.3	126.9	48,155.5
10	376.3	126.5	48,057.6
11	376.3	126.2	47,959.7
12	376.3	125.8	47,861.9
13	62.7	125.4	7,958.5
14	64.2	125.0	8,132.2
15	65.7	124.6	8,305.2
16	67.3	124.2	8,489.9
17	68.9	123.8	8,673.8
18	70.6	123.4	8,869.5
19	72.3	123.0	9,064.2
20	74.0	122.6	9,258.1
21	75.8	122.2	9,463.6
22	77.6	121.9	9,668.2
23	79.5	121.5	9,884.2
24	81.4	121.1	10,099.3
25	83.4	120.7	10,325.7

Note. Personal calculations conducted in Fractal Software.

If we present the total annual revenues graphically like in Figure 18, we can see that the revenues trend basically follows the price trend from Figure 17. Again, after the 12th year, annual revenues fall drastically as a direct consequence of the drop in electricity prices.

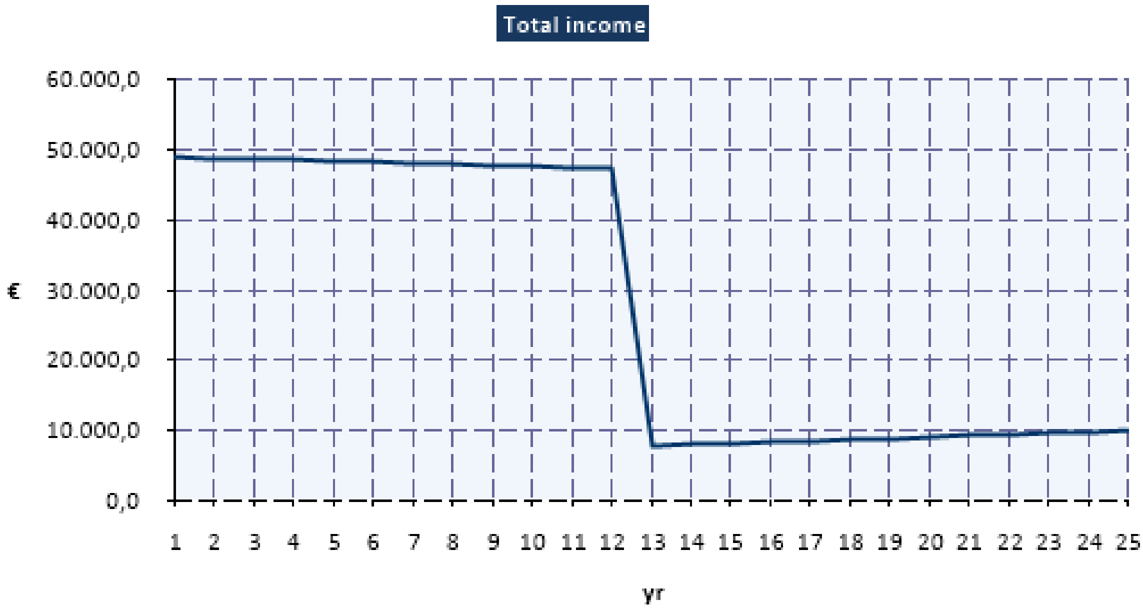

Figure 18. Graphical Presentation of the Movement of the Total Annual Revenues from the Sold Electricity during the Lifetime of the PV Power Plant "Kalesija".

This figure shows how the annual revenues from the sold electricity change during the period of 25 years of operation of the PV power plant "Kalesija". The X-axis represents time period expressed in years, and the Y-axis represents the total annual revenues from sold electricity, expressed in Euros. The figure was created in Fractal Software.

The guaranteed purchase price for the first 12 years is fixed at 376.3 €/MWh. However, Figure 18 shows that the revenues have a slight decline trend. The reason for the slight fall is the gradual decrease in electricity production due to the annual 0.20% degradation of the PV panels. In contrast, if we observe only the revenues from 13th to 25th year of operation, independently from the first 12 years, the revenues have a small incline trend despite the further reduction in electricity production due to the same rate of PV panels' degradation. The reason behind this trend is the expected growth rate of the market price of electricity at an annual level of 2.4% which has a positive impact on revenue growth and is more dominant than the negative impact of the PV panels' degradation rate of 0.20% per year.

5.1.4.3 Construction Costs

Costs of construction in the case of the PV power plant “Kalesija” refer to the costs of procurement and installation of the PV modules and inverters, the costs of structure mounting, costs of electrical equipment installment and connection to the distribution network, as well as the costs of documentation and other services. Table 16 breaks down the total costs of construction of the PV power plant “”Kalesija”.

Table 16

Construction Costs of the PV Power Plant “Kalesija”

Component	Total	Total	Total
	(€)	(€ / kW)	(%)
PV modules	167,280	1,360.0	54.7
Inverters	31,980	260.0	10.5
Mounting structure	36,900	300.0	12.1
Ground works, construction works, foundations, mounting	18,450	150.0	6.0
Electrical equipment (DC, AC cables, cabinets etc.)	18,450	150.0	6.0
Grid connection	8,000	65.0	2.6
Documentation and approvals issuing	10,000	81.3	3.3
Miscellaneous	14,553	118.3	4.8
Total investment costs	**305,613.0**	**2,484.7**	**100**

Note. Green fields were calculated automatically by the software; white and gray fields were manually calculated and entered in consultation with an expert from the project bearer company.

The total costs of construction of the PV Power Plant “Kalesija” from Table 16 amount to 305,613 €. Specific construction costs are based on component prices on the world market and amount to 2,484.7 €/kW. The trend on the world market in recent years is that the costs of basic equipment (PV modules, inverters and supporting structure) are in a steady decline due to the increase in the production of this equipment primarily in China, but also in the rest of the world. This trend means that the PV power plants are becoming more and more competitive to coal-fired power plants in terms of costs of electricity production. Figure 19 shows how each individual cost amounts to total construction costs of the PV power plant “Kalesija”.

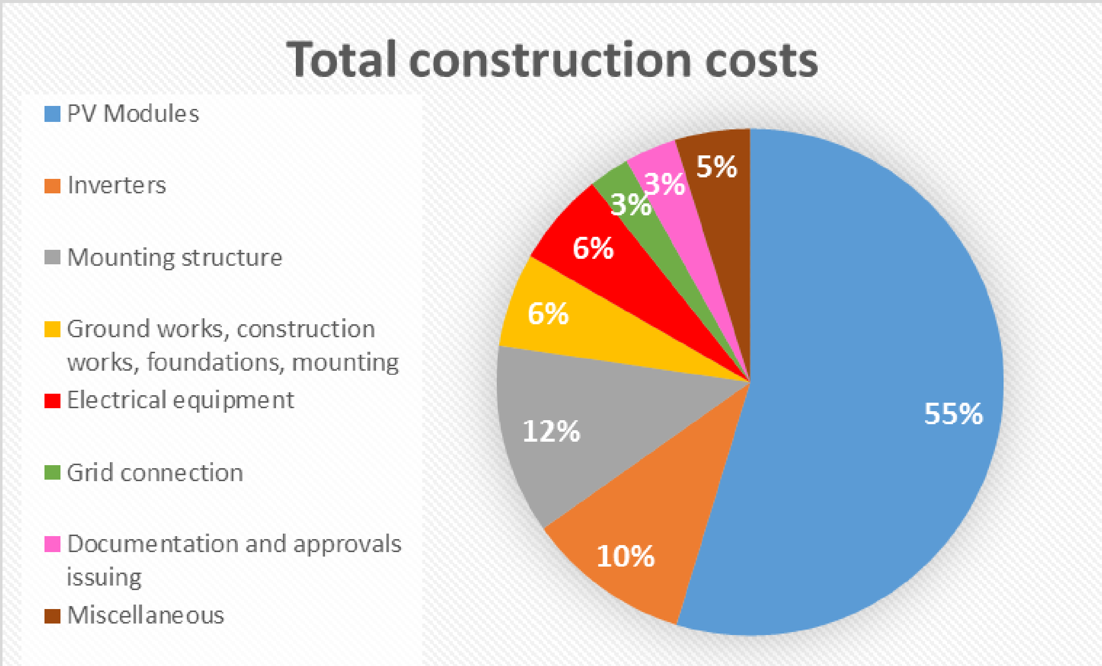

Figure 19. Breakdown of the Total Construction Costs of the PV Power Plant “Kalesija”. This figure breaks down the total construction costs into individual percentage shares of each type of costs. The figure was created on the basis of the data from Table 16.

As already said, the total costs of construction of the PV Power Plant “Kalesija” are 305,613 €. Among all individual costs, PV modules have by far the largest share in total construction costs. The market price of PV modules in 2012 was about 1,360 €/kW or 167.280 € in the absolute amount for the total number of installed PV modules. The next dominant costs are the costs of the aluminum sub-structure and costs of the inverters, which, together with the costs of the PV modules, make up about 77% of the total costs of the PV power plant “Kalesija”. In addition, there are also costs of electrical equipment and connections to the distribution network, documentation and approvals costs as well as other unexpected expenses during the project realization.

5.1.4.4 Operation and Maintenance Costs

The O&M costs of the PV power plant "Kalesija" refer in largest part to periodic maintenance of the PV panels and inverters, the payments for the concession for the use of the roof of the sports hall, and the costs of securing the equipment of the PV power plant. Table 17 shows the structure of O&M costs of the PV power plant "Kalesija". The table is divided into periodical costs, concession and fees, and maintenance and insurance subsections.

Table 17

O&M Costs of the PV Power Plant "Kalesija"

Periodical costs		
Inverter replacement	(% of inverter price)	30.00
	(€)	9,594
	(year)	12
Concession and fees		
Land / roof lease	-	per occupied surface
Required gross surface	(m^2)	1,700
Specific land lease costs	(€ / m^2)	0.30
Lease costs annual growth	(% / year)	0.00
Maintenance and insurance		
Maintenance costs	(% of investment)	0.50
Maintenance costs annual growth rate	(% / year)	1.10
Insurance costs	(% of investment)	0.10
Insurance costs annual growth rate	(% / year)	0.00

Note. Green field was calculated automatically by the software; white and gray fields were manually calculated and entered in consultation with an expert.

Table 17 shows that, among all the individual components in O&M costs, the inverters (total of 8 units) have the largest share in total O&M costs. It is realistic to expect that, during 12 years of inverter operation, at least 2 of the total installed 8 pieces of inverters will need to be replaced. There are also the costs of renting the roof of the hall from the local municipality which are fixed and annually amount to symbolic 510 € as a result of the contributions of the local municipality of Kalesija in promoting the electricity production from renewable sources. Fixed costs of insurance of plant assets amount to 305.60 €/year and relate mainly to PV panel security from damage caused by ice. Maintenance costs are estimated at 0.50% of the total value of the PV plant construction with an annual growth rate of 1.10%.

Table 18 shows the annual amounts of all O&M costs, their total and their percentage share from income, during the entire lifetime of the PV plant “Kalesija”.

Table 18

Annual O&M Costs during the Lifetime of the PV Power Plant "Kalesija"

Year	Maintenance	Fees	Insurance	Total	Total
	(€)	(€)	(€)	(€)	(% of income)
1	1,528.1	510.0	305.6	**2,343.7**	**4.79**
2	1,544.9	510.0	305.6	**2,360.5**	**4.83**
3	1,561.9	510.0	305.6	**2,377.5**	**4.88**
4	1,579.0	510.0	305.6	**2,394.7**	**4.92**
5	1,596.4	510.0	305.6	**2,412.0**	**4.97**
6	1,614.0	510.0	305.6	**2,429.6**	**5.01**
7	1,631.7	510.0	305.6	**2,447.3**	**5.06**
8	1,649.7	510.0	305.6	**2,465.3**	**5.11**
9	1,667.8	510.0	305.6	**2,483.4**	**5.16**
10	1,686.2	510.0	305.6	**2,501.8**	**5.21**
11	1,704.7	510.0	305.6	**2,520.3**	**5.26**
12	1,723.5	510.0	305.6	**2,539.1**	**5.31**
13	1,742.4	510.0	305.6	**2,558.0**	**32.14**
14	1,761.6	510.0	305.6	**2,577.2**	**31.69**
15	1,781.0	510.0	305.6	**2,596.6**	**31.26**
16	1,800.6	510.0	305.6	**2,616.2**	**30.82**
17	1,820.4	510.0	305.6	**2,636.0**	**30.79**
18	1,840.4	510.0	305.6	**2,656.0**	**29.95**
19	1,860.6	510.0	305.6	**2,676.3**	**29.53**
20	1,881.1	510.0	305.6	**2,696.7**	**29.13**
21	1,901.8	510.0	305.6	**2,717.4**	**28.71**
22	1,922.7	510.0	305.6	**2,738.6**	**28.32**
23	1,943.9	510.0	305.6	**2,759.5**	**27.92**
24	1,965.3	510.0	305.6	**2,780.9**	**27.54**
25	1,986.9	510.0	305.6	**2,802.5**	**27.14**

Note. Data are personal calculations conducted in Fractal Software.

By observing the data from Table 18, it is worth noting that the share of costs in relation to the total income is relatively small in the first 12 years due to the high guaranteed purchase price of electricity, but these shares drastically increase from 13th-25th year of the power plant's lifetime because in the same period there is a sudden decline in both the purchase price of produced electricity and total income as its direct consequence. So, although the O&M costs are not that higher in years 13-25 than in 1-12, their share in total income becomes radically bigger, which significantly endangers the profitability of the power plant. Figure 20 shows, how the O&M costs exponentially grow as the power plant's lifetime comes closer to its end.

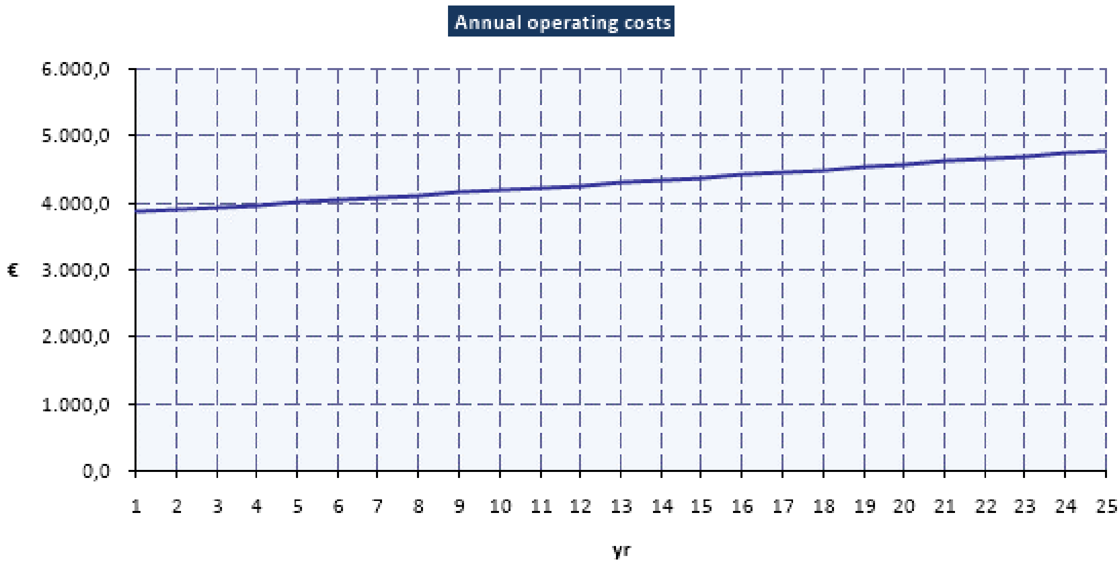

Figure 20. Graphical Presentation of the Movement of the Total O&M Costs during the Lifetime of the PV Power Plant "Kalesija".

This figure shows how the total O&M costs change during the period of 25 years of operation of the PV power plant "Kalesija". The X-axis represents time period expressed in years, and the Y-axis represents the total annual O&M costs expressed in Euros. The figure was created in Fractal Software.

5.1.4.5 Calculation of the Profitability Indicators

The final and the most important part of the case study of the PV power plant “Kalesija” is the calculation of the profitability indicators and results that determine the feasibility of building this power plant. The goal of this part of the analysis was to calculate the NPV, IRR, equity payback time, benefit-cost ratio and the LCOE as the relevant indicators of the profitability of investment in the PV power plant “Kalesija”.

In order to calculate the profitability measures except from the LCOE, it was necessary to determine the equity cash flow during the lifetime of 25 years. We already know from Table 13 that the personal participation of the Eco Energy company is 20% of the total investment value, i.e. 61,123 €, so the initial equity cash flow starts at -61,123 €. Table 19 shows the equity cash flow of the PV power plant “Kalesija” during the entire lifetime of the power plant. The table presents the annual values of gross profit without tax, net profit after taxation, the discounted net profit and, finally, the cumulative net profit, which is actually the most important column, since it presents the actual values that could be expected, after the taxation and discounting to present values are made. In addition, final column displays the payback time of the investment, i.e. the year in which the cumulative net profit turns positive.

It is important to note that the Fractal Software used for the calculation of the equity cash flow takes into account all the relevant factors presented in previous tables regarding the technical, energy and financial parameters of the PV power plant “Kalesija”. Although the input data cannot be seen in Table 19, the equity cash flow was calculated taking into account all the other expenses and costs, such as annual debt payment, interest rates on loan, annual depreciation and all the other relevant components. These expenses were taken from the previous tables (mainly from Table 13) automatically by the software, so Table 19 presents the complete and reasonably reliable equity cash flow of the PV power plant “Kalesija” during its lifetime.

Table 19

Equity Cash Flow of the PV Power Plant "Kalesija"

Year	Gross profit	Net profit	Discounted	Cumulative net profit	Payback time
	(€)	(€)	(€)	(€)	(Year)
0	-61,123	-61,123	-61,123	-61,123	
1	6,639	6,350	5,773	-55,350	
2	6,525	6,084	5,028	-50,322	
3	6,410	5,804	4,360	-45,961	
4	6,295	5,508	3,762	-42,199	
5	6,179	5,196	3,227	-38,973	
6	6,064	4,867	2,747	-36,226	
7	5,948	4,517	2,318	-33,907	
8	5,833	4,147	1,935	-31,973	
9	5,717	3,754	1,592	-30,380	
10	45,556	43,292	16,691	-13,689	
11	45,439	43,188	15,137	1,448	11
12	35,729	33,489	10,670	12,118	
13	5,401	4,860	1,408	13,526	
14	5,555	5,000	1,317	14,843	
15	5,709	5,138	1,230	16,073	
16	5,874	5,286	1,150	17,223	
17	5,925	5,332	1,055	18,278	
18	6,213	5,592	1,006	19,284	
19	6,388	5,749	940	20,224	
20	6,561	5,905	878	21,102	
21	6,746	6,072	820	21,922	
22	6,930	6,237	766	22,688	
23	7,125	6,412	716	23,404	
24	7,318	6,587	669	24,073	
25	7,523	6,771	625	24,698	

Note. Data are personal calculations conducted in Fractal Software.

The discount rate used in the calculations from Table 19 was displayed in the already mentioned Table 13 and amounts to 10%. The income tax rate used to calculate the net profit in Table 19 is 10% in BiH. Income tax represents an important variable that affects the business results of a company and is necessarily included in a typical cash flow analysis. The equity cash flow calculations showed that the investment payback period is 11 years, i.e., one year before the expiration of the official period of the sale of electricity at the guaranteed price. The invested money will be returned to the investor after 11 years of operation and from the 12th year, the investor gains the accumulated income as extra income on the already repaid investment. At the end of the lifetime, the investor should receive the total 24,698 € of cumulative net profit, which actually represents the NPV value of this project. NPV and the other profitability indicators will be displayed after the graph showing the trend in cumulative equity cash flow during the 25 years of operation.

Figure 21 is a graphical presentation created on the basis of data from Table 19 and shows the cumulative equity cash flow during the entire lifespan of the PV power plant "Kalesija" and illustrates the 11th year as the break-even point of the investment.

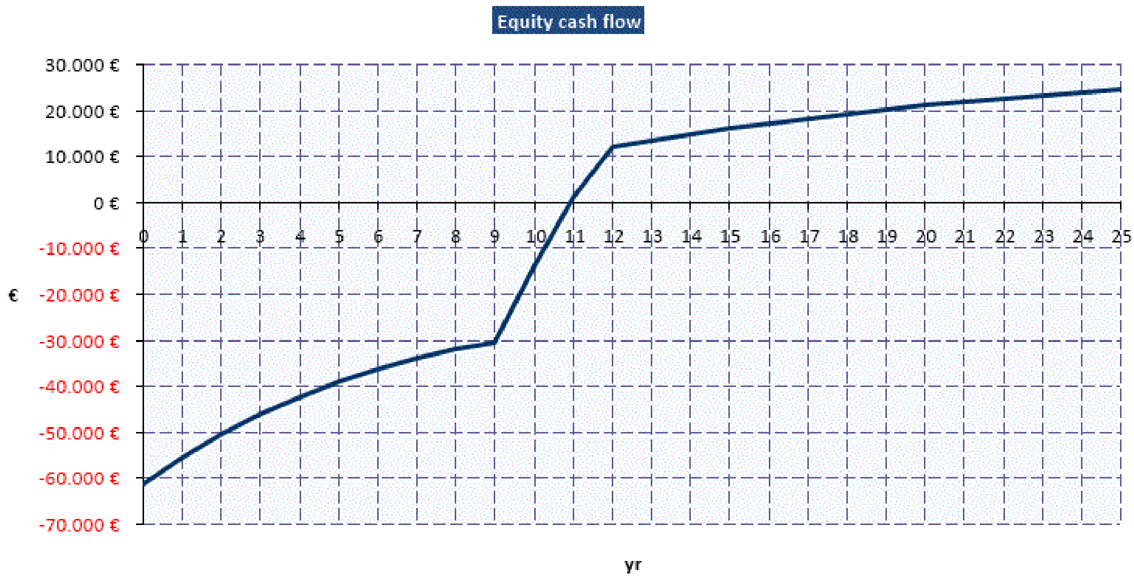

Figure 21. Graphical Presentation of the Equity Cash Flow during the Lifetime of the PV Power Plant "Kalesija".

This figure shows the trend in the movement of the equity cash flow during the period of 25 years of operation of the PV power plant "Kalesija". The X-axis represents the time period expressed in years, and the Y-axis represents the cash flow in Euros. The figure was created in Fractal Software.

Looking again at Table 19, we already know that the NPV of this project is 24,698 €, while the equity payback time is 11 years. The other two measures, i.e. the IRR and benefit-cost ratio were then easily calculated automatically by the software using the data from Table 19. Table 20 shows the results of the analysis of cost effectiveness of the construction of the PV power plant “Kalesija”, taking into account the four profitability measures, excluding the LCOE.

Table 20

Results of the Analysis of Financial Viability of the Construction of the PV Power Plant “Kalesija”

Measure of profitability	Unit	Value
IRR	(%)	14.25
NPV	(€)	24,698
Equity payback time	(year)	11
Benefit-cost ratio	-	1.40

Note. Data are personal calculations conducted in Fractal Software.

The results of the calculations of the IRR, NPV, benefit-cost ratio, as well as the time of return on investment, indicate that the investment in the construction of the PV power plant “Kalesija” is profitable and that the money invested will be returned after 11 years of operation with the projected level of electricity production, taking into account an annual degradation of the PV panels as well. The IRR of 14.25% from Table 20 is higher than the discount rate of 10%, while NPV is positive, and, in these terms, both profitability indicators suggest that the investment should be undertaken. In addition, taking into account the actual data on realized electricity production in the period 2012-2017 and the assumption that such a trend will continue in the following years, the investment return period can be shortened from 11 to 8-9 years, which could, for the remaining lifetime of the PV plant, allow accumulation of certain amounts of profit that could in part cover a drastic reduction in revenues after the expiry of the 12-year period of electricity redemption at the guaranteed price.

The final part of the financial analysis, but, certainly one of the most important when it comes to energy related costs, is the LCOE calculation. As already explained in Chapter

4, the LCOE tool calculates the average cost of production of one kWh of electricity, displayed through the NPV of the power plant during its lifetime.

In order to slightly simplify the LCOE calculation presented in Chapter 4, Section 4.1, and since there are no fuel costs when it comes to PV power plants (and other power plants based on renewable energy as well), besides the initial investment cost, only other costs taken into account will be the O&M costs (A_t from *Equation 1*), while the Fuel costs (F_t from *Equation 1*) will now be taken out of the equation. So *Equation 4* (which is basically a repetition of *Equation 1* from Chapter 4) now becomes *Equation 5*, used for final calculations of LCOE of the PV power plant "Kalesija" in this chapter.

$$\mathbf{LCOE} = \frac{I_0 + \sum_{t=1}^{n} \frac{A_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}} \tag{4}$$

$$\mathbf{LCOE} = \frac{I_0 + \sum_{t=1}^{n} \frac{A_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}} \tag{5}$$

I_t = Initial investment cost (capital expenditure)

A_t = Annual O&M costs in year (t)

F_t = Annual fuel costs in year (t)

E_t = Annual electricity produced in year (t)

r = Discount rate

n = The (expected) lifetime of the power system expressed in years

t = Year of lifetime

Table 21 shows the relevant input data of the PV power plant "Kalesija" used as the basis to calculate its LCOE value by using *Equation 5*.

Table 21

Input Data for the LCOE Calculation of the PV Power Plant "Kalesija"

Component	Unit	Value	Source
Investment expenditure (I_t)	(€)	305,613	Table 16
Annual total cost (A_t), sum of A_t after 25 years	(€/year t)	25,467	Table 22
Electricity output (E_t), sum of E_t after 25 years	(kWh/year)	1,309,702	Table 22
Discount rate (r)	(%)	10.0	Table 13
Lifetime (n)	(years)	25	Table 14
Year of lifetime (t)	(1,2,…,25)	1,2,…,25	Table 14

Note.

Table 21 displays all the input data needed for *Equation 5* in order to calculate the LCOE of the PV power plant "Kalesija". It is worth noting that the data on the sum of annual total costs and the sum of annual electricity output are displayed in the subsequent Table 22. On the basis of all the data from Table 21, the LCOE is then calculated by dividing the discounted values of all costs with the discounted values of total produced electricity during the whole lifetime of the PV power plant "Kalesija". The rate at which the values are discounted to present value is again 10%.

Table 22 shows the trends of each component from *Equation 5* for every year of the lifetime of the PV power plant "Kalesija", except from the investment expenditure which was I_0 = 305,613 € in year 0. The table displays the annual values of both real and discounted O&M costs as well as the real and discounted values of the annual electricity produced during the whole lifetime of 25 years. The final row is the sum of each of the relevant columns, i.e. the sum of all the annual values of each component, and these total values were the ones used later to calculate the final value of LCOE for the PV power plant "Kalesija".

Table 22

Annual Values of Each Component Used in the Calculation of the LCOE of the PV Power Plant "Kalesija"

Year	Undiscounted total annual cost (A_t)	Discount factor [$(1+r)^t$]	Discounted total annual cost [$A_t / (1+r)^t$]	Undiscounted total electricity produced (E_t)	Discount factor [$(1+r)^t$]	Discounted total electricity produced [$E_t / (1+r)^t$]
	(€)		(€)	(kWh)		(kWh)
1	2,344	1.1	2,160	130,100	1.1	119,908
2	2,361	1.2	2,006	129,800	1.2	110,259
3	2,378	1.3	1,862	129,500	1.3	101,387
4	2,395	1.4	1,728	129,300	1.4	93,300
5	2,412	1.5	1,604	129,000	1.5	85,791
6	2,429	1.6	1,489	128,800	1.6	78,947
7	2,448	1.8	1,383	128,500	1.8	72,593
8	2,465	1.9	1,283	128,200	1.9	66,750
9	2,484	2.1	1,192	128,000	2.1	61,425
10	2,502	2.3	1,107	127,700	2.3	56,480
11	2,520	2.5	1,027	127,500	2.5	51,974
12	2,539	2.7	954	127,200	2.7	47,789
13	2,558	2.9	886	126,900	2.9	43,942
14	2,577	3.1	822	126,700	3.1	40,435
15	2,597	3.4	764	126,400	3.4	37,179
16	2,616	3.7	709	126,200	3.7	34,212
17	2,636	4.0	659	125,900	4.0	31,457
18	2,656	4.3	612	125,600	4.3	28,924
19	2,676	4.7	568	125,400	4.7	26,615
20	2,697	5.1	528	125,100	5.1	24,472
21	2,717	5.5	490	124,800	5.5	22,500
22	2,738	6.0	455	124,600	6.0	20,704
23	2,759	6.5	423	124,300	6.5	19,037
24	2,781	7.1	393	124,100	7.1	17,517
25	2,803	7.7	365	123,800	7.7	16,106
Total			**25,467**			**1,309,702**

Note. Data are personal calculations.

On the basis of data from Table 22, we can now easily calculate the LCOE for the PV power plant "Kalesija". The two required values are the sum of the total discounted annual costs which amounts to 25,467 € and the sum of the total discounted annual electricity produced which amounts to 1,309,702 kWh. When we plug in these values in *Equation 5*, along with the investment expenditure in year 0, which amounts to 305,613 €, the

LCOE value for the PV power plant “Kalesija” has the final value of 0.2528 €/kWh. Table 23 displays the final calculation of LCOE for this power plant.

Table 23

Calculation of the LCOE of the PV Power Plant “Kalesija”

Component A: investment expenditure (I_0)	**Component B: I_0 + 25 years total of [A_t / $(1+r)^t$]**	**Component C: 25 years total of [E_t / $(1+r)^t$]**	**LCOE (B / C)**
(€)	(€)	(kWh)	(€ / kWh)
305,613	331,080	1,309,702	0.2528

Note. Data are personal calculations.

If the calculated LCOE value from Table 23 with regards to the year 2012 is compared with LCOE calculations for similar projects in some EU countries in 2012, it can generally be concluded that this value is regularly higher than the LCOE values of most of the other PV power plants in the EU countries. The main reason for this disparity lies primarily in the very high cost of capital and high interest rates in BiH compared to those in the EU, which significantly increases the investment costs in such projects conducted in BiH.

Table 24 summarizes the profitability analysis of the PV power plant “Kalesija” by providing an overview of the most important calculated profitability indicators, i.e. NPV, IRR and LCOE.

Table 24

Final Display of the NPV, IRR and LCOE of the PV Power Plant “Kalesija”

Profitability measure	**Unit**	**Value**
NPV	(€)	24,698
IRR	(%)	14.25
LCOE	(€ / kWh)	0.2528

Note.

5.2 Profitability Analysis of "Mesihovina", the First Wind Farm in Bosnia and Herzegovina

"Mesihovina" is the first ever and still the only wind farm in BiH, which has been put in operation in March, 2018. The investor is the domestic, state owned company JP Elektroprivreda HZ HB. The wind farm consists of total 22 wind turbines allocated in the south of country, i.e. in the region of Herzegovina. It mainly supplies the electricity to the nearby municipality of Tomislavgrad, while the name "Mesihovina" originates from the name of the hill where the wind farm is located.

The location of the wind farm in the south-western part of the country is suitable for the construction of wind power plants due to the large number of windy days throughout the year and due to relatively poorly populated area, enabling minimal impact on the local population and the environment. Soil characteristics are also suitable for simple and high quality foundations for the mounting of wind shafts.

Apart from simulation of the electricity production, the case study of WF "Mesihovina" is structured in the same way as the case study of the PV power plant "Kalesija", in order to provide the results that are comparable to the results of the two other power plants that were subject of a case study in this research. With this matter, section 5.2.1 will display the economic and technical indicators of the WF "Mesihovina" and section 5.2.2 is the comprehensive financial analysis.

5.2.1 Economic and Technical Indicators

According to JP Elektroprivreda HZ HB (2009), the total investment in WF "Mesihovina" amounts to 66,674,580 EUR, out of which 15% of the total investment value is covered from own funds of the investor company JP Elektroprivreda HZ HB, and 85% from bank loan at the interest rate of 4.5% (unpublished raw data). Table 25 shows these and other basic economic and technical parameters of the WF "Mesihovina" used for the later economic and financial analysis of the feasibility of its construction.

Table 25

Basic Economic and Technical Indicators of the WF "Mesihovina"

Component	Unit	Value
Project name		*Vjetroelektrana Mesihovina* [Wind Farm Mesihovina]
Investor		JP Elektroprivreda HZ HB d.d. Mostar
Total investment	(€)	66,674,280
Equity (15% of investment)	(€)	10,001,142
Loan (85% of investment)	(€)	56,673,138
Loan repayment time	(years)	15
Loan interest rate	(%)	4.5
Discount rate	(%)	10.0
Lifetime	(years)	20
Installed capacity	(MW)	44
Annual net production (with all losses included)	(MWh)	129,095
Number of operating hours at maximum installed capacity	(h)	2,921
Capacitance factor	(%)	33.5
Capacity of a single wind turbine	(MW)	2
Wind turbines: number and model		22 x ENERCON / E82-E2 (2 MW); rotor diameter 82 m; hub height 78 m

Note. Data adapted from "WF Mesihovina: economic-financial analysis [unpublished raw data]", by JP Elektroprivreda HZ HB, 2009.

Based on the results of field measurements and analysis of the collected data, the investor JP Elektroprivreda HZ HB has made a projection of the possible electricity output from the WF “Mesihovina “. For the pre-selected 22 wind turbines of the ENERCON type E82-E2 with the individual capacity of 2 MW as stated in Table 25 (total installed capacity of 44 MW), the investor established that it is possible to produce a total net of 129,095 MWh of electricity per annum. The projection of possible net annual electricity production of 129,095 MWh was calculated taking into account a factor of capacitance of the WF “Mesihovina” which is 33.5%.

5.2.2 Financial Analysis

In order to determine the price of electricity produced from wind power and the general profitability of the WF “Mesihovina”, it was necessary to determine a number of factors affecting the cost of electricity generation in wind farm. JP Elektroprivreda HZ HB (2009) stated that there are two main groups of factors that affect the costs of electricity generated from wind power, and thus the final price. These are technical and financial factors including:

- The average wind speed at the location of the wind farm, technically feasible utilization rate of wind, the type of wind turbine and its degree of utilization, the type and spatial arrangement of wind turbines, the degree of utilization of other equipment affecting the total loss in electricity generation.
- Interest rates, the required return on invested capital, the time period during which the capital is paid (unpublished raw data).

In order to conduct the profitability analysis of the WF “Mesihovina”, it was necessary to take into account similar factors as was the case with the profitability analysis of the PV power plant “Kalesija” shown in section 5.1. Sections 5.2.2.1, 5.2.2.2 and 5.2.2.3 will elaborate the revenues generated from sold electricity, construction costs and O&M costs respectively. Section 5.2.2.4 refers to the final calculation of the profitability indicators NPV, LCOE, IRR, equity payback time, benefit cost-ratio and the display of the results.

5.2.2.1 Revenues

In the same way as it was the case with the PV power plant “Kalesija”, the annual revenues of the WF “Mesihovina” were calculated by multiplying the total annual net production with the purchase price of electricity. According to JP Elektroprivreda HZ HB (2009), the guaranteed price for the electricity produced in wind farms in the incentive system of BiH amounts to 130.7 BAM/MWh or 66.83 EUR/MWh, converted at the exchange rate of 1 EUR = 1.95583 BAM (unpublished raw data).

Unlike the incentive system of BiH concerning the PV power plants which lasts 12 years, a wind farm has the right to sell the produced electricity at the guaranteed price during its entire lifetime, which is 20 years. Since the price remains the same during the whole operation period and there is no reduction in electricity production due to equipment degradation like it was the case with the PV power plant “Kalesija” (degradation of PV panels), we can simplify the revenues calculation and express it as a single value representing the average annual revenue during the entire lifetime. This is easily done by multiplying the guaranteed price of 66.83 €/MWh with the estimated average annual electricity production already displayed in Table 25, i.e. 129,095 MWh. So after the calculation is done, the average annual revenue from the produced electricity by WF “Mesihovina” amounts to 8,627,418.85 €.

5.2.2.2 Construction Costs

For the construction of the WF “Mesihovina”, it was necessary to make the feasibility studies and project documentation, as well as to obtain various permits. All these costs fall into a category of construction costs. In addition to these costs, and besides the main costs of construction of wind shafts with wind turbines, there are also costs for the construction of a transformer station (substation) for connecting the power plant to the transmission network, as well as the costs of the internal cable network. Table 26 breaks down the structure of these construction costs into individual components.

Table 26

Construction Costs of the WF "Mesihovina"

Type of cost	Share	Value
	(%)	(€)
Project development	3.30	2,200,000
Loan insurance	1.95	1,300,000
Construction works	4.17	2,780,530
Construction of 110 kV / 20 kV substation + 110 kV power line	6.19	4,125,000
20 kV internal cable network and 0.69 kV / 20 kV substation + construction works	2.17	1,448,750
Cost of wind turbine shaft (including transportation and assembly)	79.52	53,020,000
Interest expense for construction financing	1.80	1,200,000
Estimates of other unforeseen costs	0.90	600,000
Total	**100.00**	**66,674,280**

Note. Data adopted from "WF Mesihovina: economic-financial analysis [unpublished raw data]", by JP Elektroprivreda HZ HB, 2009.

It is obvious that the investment costs of the project WF "Mesihovina" are much higher than those of the PV power plant "Kalesija", which is quite understandable when comparing a typical wind farm with an investment in an average PV power plant. WF "Mesihovina" is a far larger project, but should yield greater returns on investment than those of the PV power plant "Kalesija" and should prove to be of a greater national interest for the energy sector. Figure 22 shows how each individual component adds to the total construction costs of the WF "Mesihovina".

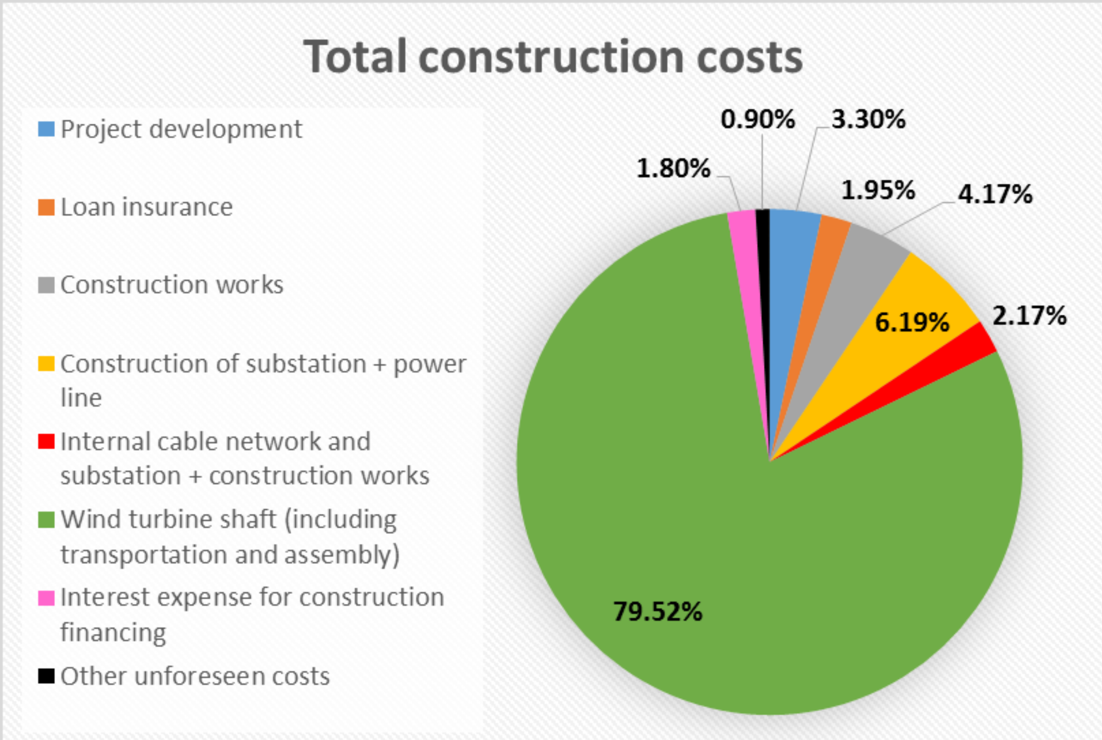

Figure 22. Breakdown of the Total Construction Costs of the WF "Mesihovina". This figure breaks down the total construction costs into individual percentage share of each type of costs. The figure was created on the basis of the data from Table 26.

Figure 22 shows that, in percentage terms, the costs of wind turbine shaft with its transportation and assembly costs, have of course by far the largest share in the total construction costs of WF "Mesihovina", i.e. 79.52% of the total construction costs. The second biggest cost component are the costs of construction of the 110 kV / 20 kV substation and 100 kV power line with the 6.9% share in the total construction costs. All the other costs have relatively small shares, especially compared to the costs of the wind turbine shaft, however taking into consideration the huge value of the total investment, even these costs are significant expenses.

5.2.2.3 Operation and Maintenance Costs

O&M costs represent one of the key parameters for assessing the profitability of the WF "Mesihovina" as well as for the calculation of the LCOE. Table 27 presents the total O&M costs of the WF "Mesihovina" during its lifetime of 20 years.

Table 27

O&M Costs of the WF "Mesihovina"

Type of cost	1st & 2nd year		From 3rd to 20th year	
	(€ / year)	(%)(1)	(€ / year)	(%)(2)
Wind turbine management and maintenance services (during warranty period)	642,635.00	9.2	0.00	0.0
Wind turbine management and maintenance services (out of warranty period)	0.00	0.0	835,425.50	11.9
Supervision of WF "Mesihovina"	38,280.00	0.5	38,280.00	0.5
Maintenance of access roads and green areas	25,080.00	0.4	25,080.00	0.4
Own consumption of electricity	51,480.00	0.7	51,480.00	0.7
Compensation fees	284,861.14	4.1	284,861.14	4.1
Insurance	257,683.37	3.7	257,683.37	3.7
Management and technical staff	201,545.91	2.9	201,545.91	2.9
External services	18,480.00	0.3	18,480.00	0.3
Total	**1,520,045.43**	**21.7**	**1,712,835.93**	**24.5**

Note. (1)(2)Annual O&M costs in ratio to total annual revenue, expressed in percentages. Calculated as: Annual O&M costs / Total annual revenue. Data adapted from "WF Mesihovina: economic-financial analysis [unpublished raw data]", by JP Elektroprivreda HZ HB, 2009.

Table 27 shows that the total annual O&M costs of the WF "Mesihovina" during its lifetime, range from 1,520,045 € in the first two years during the warranty period, to 1,712,835 € from third year until the end of the lifetime, i.e. when out of the warranty. When observed as a ratio to total annual revenues, the O&M costs during the first two years amount to 21.7% of the total annual revenues, and 24.5% during the remaining years until the end of the lifetime.

The difference in the amount of costs of wind turbine management and maintenance services between the period of warranty and the period without the warranty is due to different prices of maintenance during the two periods. The contracted maintenance price during the period of warranty amounts to 0.005 €/kWh and is lower than the price of 0.0065 €/kWh during the period from 3rd to 20th year of operation, i.e. when out of warranty (JP Elektroprivreda HZ HB, 2009, unpublished raw data). The absolute values of other O&M costs remained the same over the two periods.

5.2.2.4 Calculation of the Profitability Indicators

The final part of the financial analysis was conducted in the same way as with the PV power plant "Kalesija". The equity cash flow is displayed first as the basis for the calculation of NPV and IRR, as well as the estimation of the equity payback time, followed by the calculation of the LCOE. Table 28 displays the equity cash flow of the WF "Mesihovina" during its lifetime. The most important measure from the table is naturally the cumulative net profit, since this is the actual equity after the inclusion of taxes and after discounting the amounts to present value.

Table 28

Equity Cash Flow of the WF "Mesihovina"

Year	Gross profit	Net profit	Discounted	Cumulative net profit	Payback time
	(€)	(€)	(€)	(€)	(Year)
0	-10,002,689	-10,002,689	-10,002,689	-10,002,689	
1	2,948,404	2,908,765	2,664,332	-7,358,358	
2	2,940,231	2,889,137	2,387,716	-4,970,641	
3	2,932,016	2,868,919	2,155,461	-2,815,180	
4	2,923,761	2,848,088	1,945,282	-869,898	
5	2,915,464	2,826,616	1,755,106	885,208	5
6	2,907,126	2,804,477	1,583,054	2,468,262	
7	2,898,746	2,781,641	1,427,422	3,895,684	
8	2,890,324	2,758,080	1,286,665	5,182,349	
9	2,811,861	2,733,762	1,159,382	6,341,731	
10	2,873,354	2,708,653	1,044,303	7,386,034	
11	2,864,806	2,682,722	940,278	8,326,311	
12	1,956,194	1,755,911	559,487	8,885,799	
13	3,103,007	2,330,208	674,978	9,560,777	
14	3,349,729	2,531,446	666,609	10,227,386	
15	3,609,149	2,743,175	656,694	10,884,080	
16	9,146,366	8,231,729	1,791,464	12,675,544	
17	9,405,640	8,465,076	1,674,770	14,350,314	
18	9,677,609	8,709,848	1,566,543	15,916,857	
19	9,962,270	8,966,043	1,466,020	17,382,877	
20	10,246,853	9,222,168	1,370,816	18,753,693	

Note. Data are personal calculations conducted in Fractal Software.

As it was displayed earlier in Table 25, the personal equity participation of the investor JP Elektroprivreda HZ HB in the project WF "Mesihovina" is 15% of the total investment costs, i.e. 10,002,689 €. The rest is financed through a bank loan and the related costs, along with all the other costs were entered manually in Fractal Software and were included in the calculation of the equity cash flow presented in Table 28. As we can see the investment is returned after only five years, which is significantly better of the equity payback time of the PV power plant “Kalesija”. Figure 23 is a graphical presentation created on the basis of the data from Table 28 and shows the cumulative equity cash flow for the entire lifespan of the WF “Mesihovina” and illustrates the 5th year as the financial break-even point of the investment.

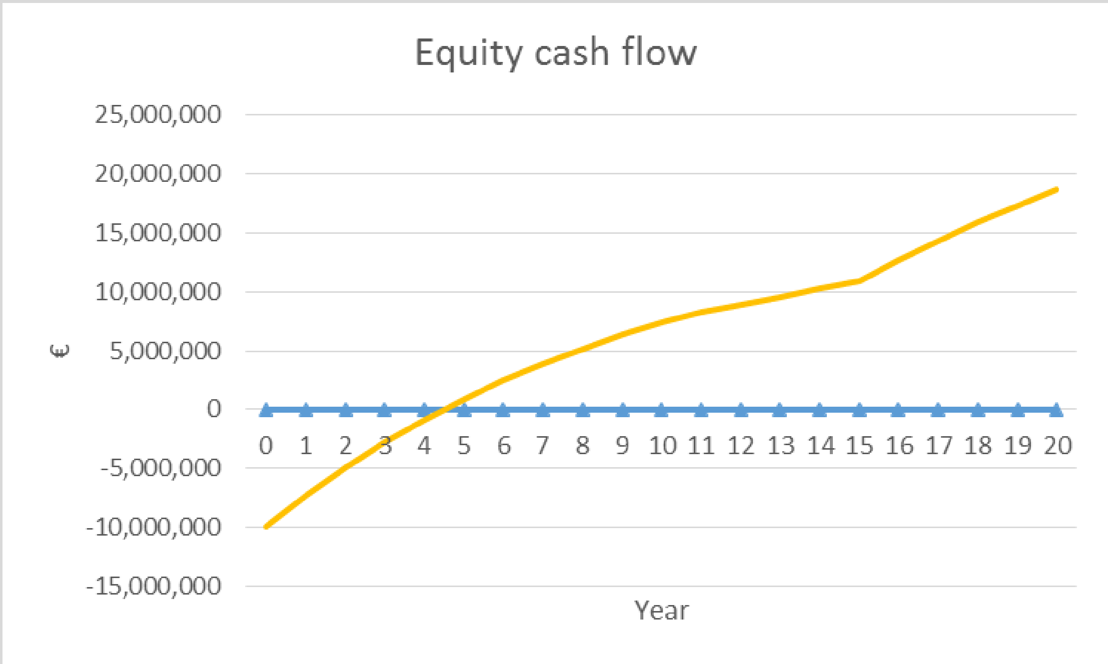

Figure 23. Graphical Presentation of the Equity Cash Flow during the Lifetime of the WF “Mesihovina”.

This figure shows the trend in the movement of the equity cash flow during the period of 20 years of operation of the WF “Mesihovina”. The X-axis represents time period expressed in years, and the Y-axis represents the cash flow expressed in Euros.

As we can see from Figure 23, the cumulative net profit goes from the initial negative to a positive value in the fifth year of operation, which allows a relatively quick repayment of the investment and a significant accumulation of profits by the end of lifetime of the power plant. Compared to the PV power plant “Kalesija” analyzed in section 5.1, by which the investment is payed off after 11 years, the break-even point of the WF “Mesihovina” is obviously much earlier.

Besides the NPV and equity payback time presented in Table 28, Fractal Software enabled the automatic calculation of the IRR and benefit-cost ratio as well. Table 29 shows the results of the analysis of cost effectiveness of the construction of the WF “Mesihovina” with regards to these four profitability indicators.

Table 29

Results of the Analysis of Financial Viability of the Construction of the WF “Mesihovina”

Measure	Unit	Value
Internal rate of return (IRR)	(%)	29.00
Net present value (NPV)	(€)	18,753,693
Equity payback time	(years)	5
Benefit-cost ratio	-	2.87

Note. Data are personal calculations conducted in Fractal Software.

Calculated indicators of the profitability analysis of the investment in the construction of the WF “Mesihovina” from Table 29 show that the investment in this power plant will be profitable after only five years. In addition, a considerably good 29% IRR is expected, while the projected NPV is undoubtedly a positive value and amounts to significant 18,753,693 €. Making the decision on the basis of these values, it is clear that the investment is certainly profitable and should be undertaken.

The last calculation to round up the profitability analysis of the WF “Mesihovina” is the LCOE measure, calculated with *Equation 5* (see section 5.4.1.5), i.e. the same one used for the LCOE calculation of the PV power plant “Kalesija”. Again, like in the case of the “Kalesija” power plant, there are no fuel costs, so the O&M costs actually represent the total annual costs (A_t). Table 30 provides an overview of these and all the other input data used to calculate the LCOE using *Equation 5*. Some of the data are from the subsequent tables.

Table 30

Input Data for the LCOE Calculation of the WF "Mesihovina"

Component	Unit	Value	Source
Investment expenditure (I_t)	(€)	66,674,280	Table 25
Annual total cost (A_t), sum of A_t after 20 years	(€/year t)	14,247,736	Table 31
Electricity output (E_t), sum of E_t after 20 years	(kWh/year)	1,105,911,927	Table 31
Discount rate (r)	(%)	10	Table 25
Lifetime (n)	(years)	20	Table 25
Year of lifetime (t)	(1,2,…,20)	1,2,…,20	Table 25

Note.

Annual total cost (A_t) and electricity output (E_t) from Table 30 were calculated in the subsequent Table 31. More precisely, Table 31 shows the trends of real and discounted O&M costs of the WF "Mesihovina" during 20 years of operation as well as trends of projected annual electricity production with its discounted values. The discount rate is again 10%.

Table 31

Annual Values of Each Component Used in the Calculation of the LCOE of the WF "Mesihovina"

Year	Undiscounted total annual cost (A_t)	Discount factor [$(1+r)^t$]	Discounted total annual cost [$A_t / (1+r)^t$]	Undiscounted total electricity produced (E_t)	Discount factor [$(1+r)^t$]	Discounted total electricity produced [$E_t / (1+r)^t$]
	(€)		(€)	(kWh)		(kWh)
1	1,520,045	1.1	1,381,859	129,900,000	1.1	118,090,909
2	1,520,045	1.2	1,256,236	129,900,000	1.2	107,355,372
3	1,712,835	1.3	1,286,878	129,900,000	1.3	97,595,793
4	1,712,835	1.5	1,169,889	129,900,000	1.5	88,723,448
5	1,712,835	1.6	1,063,536	129,900,000	1.6	80,657,680
6	1,712,835	1.8	966,851	129,900,000	1.8	73,325,164
7	1,712,835	1.9	878,955	129,900,000	1.9	66,659,240
8	1,712,835	2.1	799,050	129,900,000	2.1	60,599,309
9	1,712,835	2.4	726,409	129,900,000	2.4	55,090,281
10	1,712,835	2.6	660,372	129,900,000	2.6	50,082,073
11	1,712,835	2.9	600,338	129,900,000	2.9	45,529,158
12	1,712,835	3.1	545,762	129,900,000	3.1	41,390,143
13	1,712,835	3.5	496,147	129,900,000	3.5	37,627,403
14	1,712,835	3.8	451,043	129,900,000	3.8	34,206,730
15	1,712,835	4.2	410,039	129,900,000	4.2	31,097,027
16	1,712,835	4.6	372,763	129,900,000	4.6	28,270,025
17	1,712,835	5.1	338,875	129,900,000	5.1	25,700,022
18	1,712,835	5.6	308,068	129,900,000	5.6	23,363,657
19	1,712,835	6.1	280,062	129,900,000	6.1	21,239,688
20	1,712,835	6.7	254,602	129,900,000	6.7	19,308,807
Total			**14,247,736**			**1,105,911,927**

Note. Data are personal calculations.

We can now calculate the LCOE for the WF "Mesihovina" by taking the two required values from Table 31, i.e. the sum of the total discounted annual costs which amounts to 14,247,736 € and the sum of the total discounted annual electricity produced which amounts to 1,105,911,927 kWh. When we input these values in *Equation 5*, along with the investment expenditure in year 0, which in this case amounts to 66,674,280 €, the final LCOE value for the WF "Mesihovina" is 0.0732 €/kWh. Table 32 presents the final calculation of the LCOE for this power plant.

Table 32

Calculation of the LCOE of the WF "Mesihovina"

Component A: investment expenditure (I_0)	**Component B: I_0 + 20 years total of [$A_t / (1+r)^t$]**	**Component C: 20 years total of [$E_t / (1+r)^t$]**	**LCOE (B / C)**
(€)	(€)	(kWh)	(€ / kWh)
66,674,280	80,922,016	1,105,911,927	0.0732

Note. Data are personal calculations.

The calculated LCOE will be compared to the LCOE values of the other two power plants in Chapter 7 of this paper. Table 33 summarizes the profitability analysis of the WF "Mesihovina" by providing an overview of the most important calculated profitability indicators, i.e. NPV, IRR and LCOE.

Table 33

Final Display of the NPV, IRR and LCOE of the WF "Mesihovina"

Profitability measure	**Unit**	**Value**
NPV	(€)	18,753,693
IRR	(%)	29.00
LCOE	(€ / kWh)	0.0732

Note. Data are personal calculations.

5.3 Profitability Analysis of "Block 7 Tuzla", the Planned Expansion of the Coal-Fired Power Plant in Bosnia and Herzegovina

Coal as a primary energy source, regardless of the negative consequences that combustion in large combustion plants has on the environment, still occupies an important place in the production of energy from fossil fuels in the world. According to World Energy Council (2016), about 40% of the total energy produced in the world comes from coal as primary energy source (p. 3). In this regard, the largest share of coal consumption as the energy source refers to the use in thermal power plants for the production of electric and/or thermal energy.

This is no different in BiH, where coal-fired power plants are still the most important energy producers in the country. However, high costs of building new highly efficient coal-fired power plants with applied GHG emission-limiting technologies, as well as the EU policies for gradual reduction (movement towards complete closure) of coal-fired power plants have now seriously put into question the plans to further increase production capacities in such power plants.

"Block 7 Tuzla" is the latest planned investment in the expansion of the existing coal-fired power plant called "*Termoelektrana Tuzla* [Thermal Power Plant Tuzla]", located in Tuzla, the third largest city in BiH. "Thermal Power Plant Tuzla" is a power plant complex consisted of 6 production units, i.e. 6 "blocks" out of which blocks 1 and 2 have been completely shut down because their lifetime has expired. So, currently 4 blocks are in operation, while the construction of the 7th production unit, i.e. "Block 7 Tuzla" should start in the second half of 2018 or in 2019. The majority of the investment will be funded by a foreign investor, a consortium from China.

The justification of the expansion of "Thermal Power Plant Tuzla" and further investment in coal-fired electricity production despite the contrary EU trends that BiH is trying to follow, lies in the fact that the existing production units of this particular power plant are quite old now and are nearing the end of their lifetime. Large dependence on the power supply from this power plant requires urgent new investments. Table 34 shows the current state of all the production units of "Thermal Power Plant Tuzla", in order to better understand the need for this newly planned investment.

Table 34

Current State of "Thermal Power Plant Tuzla" and its Production Units

Production unit	Start of operation	Current state	Installed capacity	Possible electricity production
(name)	(year)		(MW)	(GWh)
Block 1	1963	Shut down	32	-
Block 2	1964	Shut down	32	-
Block 3	1966	In operation	100	462
Block 4	1971	In operation	200	1,078
Block 5	1974	In operation	200	1,078
Block 6	1978	In operation	215	1,103
Total			**715**	**3,721**

Note. The installed capacities of Block 1 and Block 2 have not been taken into account in the calculation of the total installed capacity since they are not operating anymore. Adapted and modified from "*Strateški plan i program razvoja energetskog sektora Federacije Bosne i Hercegovine* [Strategic Plan and Development Program of the Energy Sector of the Federation of Bosnia and Herzegovina]", by Government of Federation of Bosnia and Herzegovina, 2008, p. 52, Sarajevo, BA, retrieved from: http://www.fbihvlada.gov.ba/bosanski/izdvajamo/SPP-sept-08-PRIJEDLOG.pdf

Data from table 34 show that the situation in terms of age of the production units of "Thermal Power Plant Tuzla" is strongly unfavorable. Two blocks have been completely shut down while 4 other (especially Block 3) are getting seriously close to the end of their lifetime which is usually around 40 years. Blocks 3 and 4 already needed to be and have been revitalized to extend their lifespan, but also to reduce the harmful emissions of gases and solid particles from large combustion chambers.

Precisely these facts regarding aging and scarcity of production capacities call for immediate action to build replacement capacities with new high efficiency technologies that will fully meet environmental protection requirements and enable further production and distribution of electricity from this for the state of BiH very important thermal power plant. “Block 7 Tuzla” is expected to solve these problems, so there is an obvious need for the economic and financial analysis of the profitability of its construction. Section 5.3.1 will elaborate the most important economic and technical indicators of “Block 7 Tuzla”, while section 5.3.2 will include the comprehensive financial analysis of this project.

5.3.1 Economic and Technical Indicators

The main responsible for the preparation, construction and later exploitation of the new “Block 7 Tuzla” is the domestic, state owned company JP Elektroprivreda BiH d.d. Sarajevo. “Block 7 Tuzla”, with a planned installed capacity of 450 MW, is expected to be the replacement capacity for the already shut down blocks 1 and 2 (together 64 MW capacity) as well as for the currently active Block 3 (100 MW) and Block 4 (200 MW) whose lifetime is near the end. The total installed capacity of blocks 1, 2, 3 and 4 is 364 MW and should be completely replaced by Block 7 with its 450 MW of installed capacity.

The construction of “Block 7 Tuzla” has been proclaimed by the Government of the Federation of BiH as the project of public interest for the whole country and after announcing the international tender for the selection of the best partner for the construction, the offer of a consortium from China has ultimately remained as the only valid offer and an obvious choice. The investor from China offered the construction of “Block 7 Tuzla” with the basic technical parameters shown in Table 35.

Table 35

Basic Technical Indicators of "Block 7 Tuzla"

Component	Unit	Value
Project name		Block 7 Tuzla
Investor		JP Elektroprivreda BiH d.d. Sarajevo
Gross installed capacity	(MW)	450
Net installed capacity	(MW)	414.03
Number of operating hours at maximum installed capacity	(hours / year)	7000
Net efficiency in condensation mode	(%)	42
Net efficiency in wintertime	(%)	45.90
The average net efficiency for 7000 h of operation	(%)	43.60
Availability in the 1st year of warranty period	(%)	88.00
Availability in the 2nd year of warranty period	(%)	90.00
Work mode		Cogeneration
Type of technology		BAT (Best Available Techniques)
NO_x emissions	(mg / Nm^3)	< 200
SO_2 emissions	(mg / Nm^3)	< 150
Emissions of solid particles	(mg / Nm^3)	< 10
Construction time	(months)	56
Warranty period since signing block takeover protocol	(months)	24
Lifetime	(years)	25

Note. mg – milligram; Nm^3 – standard cubic meter; Data adapted from "*Informacija o aktivnostima na izboru projektnog partnera za zajedničko ulaganje u projekat izgradnje Bloka 7 u TE Tuzla: treća faza tenderskog procesa* [Information About the Activities on the Choice of the Project Partner for Joint Investment in the Construction Project of Block 7 Tuzla: Third Stage of the Tendering Process]", by JP Elektroprivreda BiH d.d.

Sarajevo, 2014(b), pp. 7, 8, 18 & 21, retrieved from https://predstavnickidom-pfbih.gov.ba/upload/file/sjednice/31_sjednica/28.pdf

Besides many obvious advantages of "Block 7", such as increased installed capacity or whole new lifetime of the power plant production unit, when compared to blocks that "Block 7 Tuzla" needs to replace, the crucial advantage are the enormous reductions in emissions of environmentally harmful gases and particles, i.e. in Table 35 stated emissions of NO_x, SO_2 and solid particles. This is especially important in order to stay in compliance with the EU directives on environmental protection. Figure 24 shows the enormous improvement in the reduction of such emissions that "Block 7 Tuzla" brings in comparison to the blocks 3 and 4 that it needs to replace.

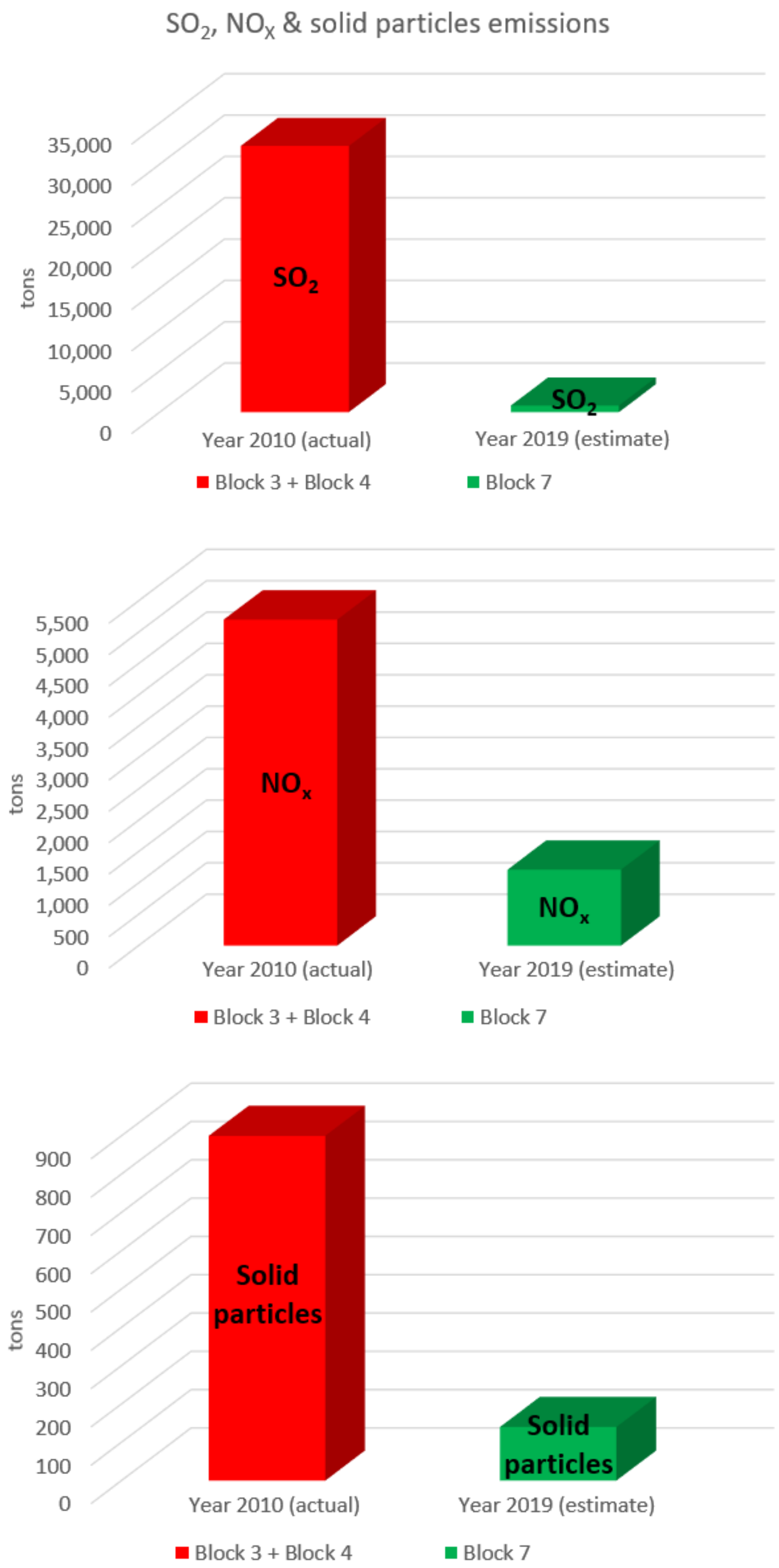

Figure 24. SO_2, NO_x and Solid Particles Emission Comparison between Blocks 3, 4 and 7.

This figure illustrates how the actual measured emissions of SO_2, NO_x and solid particles of Blocks 3 and 4 observed together, compare to the estimated 2019 emissions of Block

7, the production unit set to replace the existing two blocks. Adapted and modified from "*Informacija o aktivnostima na izboru projektnog partnera za zajedničko ulaganje u projekat izgradnje Bloka 7 u TE Tuzla: treća faza tenderskog procesa* [Information About the Activities on the Choice of the Project Partner for Joint Investment in the Construction Project of Block 7 Tuzla: Third Stage of the Tendering Process]", by JP Elektroprivreda BiH d.d. Sarajevo, 2014(b), p. 8, retrieved from https://predstavnickidom-pfbih.gov.ba/upload/file/sjednice/31_sjednica/28.pdf

Figure 24 clearly shows that the measured SO_2, NO_x and solid particles emissions from the existing and currently operating blocks 3 and 4 are multiple times greater than the planned emissions from Block 7. This is a very important reason for the urgent construction of "Block 7 Tuzla" since harmful emissions from its combustion chamber would be reduced by up to 20 times of the emissions from the existing production units, i.e. blocks of "Thermal Power Plant Tuzla".

Regarding the financial aspects of the investment in the construction of "Block 7 Tuzla, JP Elektroprivreda BiH d.d. Sarajevo (2014b) stated that there are two possible financing options: Preferential Buyer's Credit (PBC) marked as model A, and Buyer's Credit (BC) marked as model B (pp. 16-17). Table 36 provides only the overview of the most important components of both options, but the NPV and IRR values of the project for each model of financing will be shown in section 5.3.2.

Table 36

Financing Options for the Construction of "Block 7 Tuzla"

Model of financing A – Preferential Buyer's Credit (PBC Credit)		
Component	Unit	Value
Total net value of investment	(€)	785,650,000
- *of which equipment*	(€)	*515,359,956*
- *of which construction*	(€)	*254,376,347*
- *of which services*	(€)	*15,913,696*
Equity (15 % of investment)	(€)	117, 847,500
Loan (85 % of investment)	(€)	667,802,500
Grace period	(years)	5
Loan repayment time	(years)	15
Loan interest rate	(%)	2
Commitment fee	(%)	0.25
Management fee	(%)	0.25
Model of project		Turnkey
Discount rate	(%)	10

(*continued*)

(*continued*)

Model of financing B – Buyer's Credit (BC Credit)

Component	Unit	Value
Total net value of investment	(€)	835,000,000
- *of which equipment*	(€)	*547,731,895*
- *of which construction*	(€)	*270,354,801*
- *of which services*	(€)	*16,913,303*
Equity (15% of investment)	(€)	125,250,000
Loan (85% of investment)	(€)	709,750,000
Grace period	(years)	5
Loan repayment time	(years)	10
Loan interest rate	(%)	6 month Euro Libor rate + 3%
Commitment fee	(%)	0.25
Management fee	(%)	0.25
Model of project		Turnkey
Discount rate	(%)	10

Note. Data adapted from "*Informacija o aktivnostima na izboru projektnog partnera za zajedničko ulaganje u projekat izgradnje Bloka 7 u TE Tuzla: treća faza tenderskog procesa* [Information About the Activities on the Choice of the Project Partner for Joint Investment in the Construction Project of Block 7 Tuzla: Third Stage of the Tendering Process]", by JP Elektroprivreda BiH d.d. Sarajevo, 2014(b), pp. 16-17, retrieved from https://predstavnickidom-pfbih.gov.ba/upload/file/sjednice/31_sjednica/28.pdf

5.3.2 Financial Analysis

If we take the data on the planned maximum installed capacity of "Block 7 Tuzla" which is 450 MW and in addition 7,000 hours as the number of annual operating hours at this capacity (see Table 35), by multiplying them we can easily calculate that Block 7 would be able to produce the total of 3,150,000 MWh or 3,150 GWh of electricity per annum. Taking into consideration that the part of this energy will be spent for own needs of the Block 7 and part for the district heating systems of the city of Tuzla and surrounding municipalities as well, it is necessary, besides the gross produced quantities, to know the net produced quantities of electricity, i.e. the amount of electricity that will be injected into the transmission network of BiH. The total revenues from the sale of electricity will be calculated based on this value, i.e. net amount of electricity injected into the transmission network.

For the net installed capacity of 414 MW listed in Table 35 and 7,000 hours of annual operation time, it is possible to produce 2,898 GWh of electricity. In addition, due to possible unforeseen technical failures, the project bearer JP Elektroprivreda BiH has made an estimation that the availability of the installed capacity in the first year will be around 88% (Table 35), which means that the expected total energy production after the first year of operation of "Block 7 Tuzla" amounts to 2,550 GWh. This value of the net produced electricity in the first year will be the basis for the later calculations.

Section 5.3.2.1 will provide an overlook of the annual revenues during the 25 year lifetime of "Block 7 Tuzla". Sections 5.3.2.2 and 5.3.2.3 will elaborate the related construction and O&M costs respectively, while section 5.3.2.4 is the final calculation of the profitability indicators, namely: NPV, IRR, equity payback time, benefit-cost ratio and LCOE.

5.3.2.1 Revenues

In order to calculate the annual revenues, we simply need to multiply the price at which the electricity is sold with the annual net electricity produced and injected into the transmission network of BiH. According to JP Elektroprivreda BiH (2014a), the price at which the produced electricity would be sold amounts to 56.75 €/MWh, and this price is not expected to change during the whole lifetime of Block 7 (p. 31). However, the already calculated net electricity produced during the first year and injected into the transmission system amounts to 2,550 GWh, or 2,550,420 MWh. This amount was calculated taking into account the 88% availability of the total installed capacity during the first year of operation. During the second year, as stated earlier in Table 35, the estimated availability of the installed capacity is 90%, so the expected annual electricity produced and sold in the second year of operation amounts to 2,608,390 MWh. From the third year until the end of the lifetime, the expectation is that there would be no deficiencies in these terms and that the Block 7 would operate at its maximum installed capacity, so the estimated annual electricity produced and sold from 3rd year until the end of the lifetime amounts to approximately 2,898,210 MWh each year. Table 37 displays these data for each year of the lifetime including the final calculation of the total annual revenues, calculated as the multiplication of the two factors described above.

Table 37

Estimated Annual Revenues of "Block 7 Tuzla"

Year	Electricity price	Annual electricity sold	Total income
	(€/MWh)	(MWh)	(€)
1	56.75	2,550,420	144,736,335
2	56.75	2,608,390	148,026,133
3	56.75	2,898,210	164,473,418
4	56.75	2,898,210	164,473,418
5	56.75	2,898,210	164,473,418
6	56.75	2,898,210	164,473,418
7	56.75	2,898,210	164,473,418
8	56.75	2,898,210	164,473,418
9	56.75	2,898,210	164,473,418
10	56.75	2,898,210	164,473,418
11	56.75	2,898,210	164,473,418
12	56.75	2,898,210	164,473,418
13	56.75	2,898,210	164,473,418
14	56.75	2,898,210	164,473,418
15	56.75	2,898,210	164,473,418
16	56.75	2,898,210	164,473,418
17	56.75	2,898,210	164,473,418
18	56.75	2,898,210	164,473,418
19	56.75	2,898,210	164,473,418
20	56.75	2,898,210	164,473,418
21	56.75	2,898,210	164,473,418
22	56.75	2,898,210	164,473,418
23	56.75	2,898,210	164,473,418
24	56.75	2,898,210	164,473,418
25	56.75	2,898,210	164,473,418

Note. Data are personal calculations.

5.3.2.2 Construction Costs

The construction costs actually refer to the initial investment amount, the value of money needed to put the power plant into the operation, so all the costs prior to the start of operating, are included here. They have to be differentiated from all the other costs that emerge during the operating lifetime of the power plant, such as O&M or fuel costs. The construction costs differ between each other in the two mentioned financing scenarios. The total investment amount under PBC Credit is lower than the one of BC credit. Table 38 displays the construction costs per component in both of these financing models.

Table 38

Construction Costs of "Block 7 Tuzla"

Component	Value estimation under financing scenario A (PBC Credit)	Value estimation under financing scenario B (BC Credit)
	(€)	(€)
Equipment	515,359,956	547,731,895
Construction works	254,376,347	270,354,801
Services	15,913,696	16,913,303
Total	**785,650,000**	**835,000,000**

Note. Data adapted from Table 36.

Although the total net values of construction costs differ for the two financing models, the relative shares of each individual component in the total amount of construction costs are basically the same for the both scenarios. Figure 25 shows graphically how each of these components add up to the total construction costs. The graph is applicable for both financing scenarios.

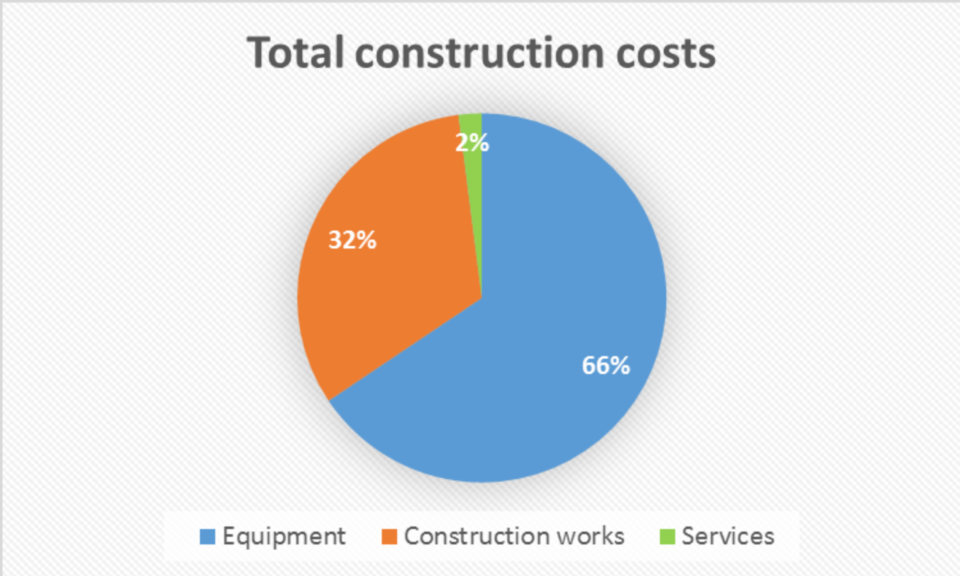

Figure 25. Breakdown of the Total Construction Costs of "Block 7 Tuzla".

This figure breaks down the total construction costs into individual percentage share of each type of costs. The figure was created on the basis of the data from Table 38.

5.3.2.3 Operation and Maintenance Costs

According to the study of the energy sector in BiH, made by Granić et al. (2008), fixed and variable O&M costs for the planned "Block 7 Tuzla" amount to 3 €/kW/month for the fixed costs and 4.7 €/MWh for the variable costs (p. 30). On the basis of these values, it is possible now to calculate the total annual fixed and variable O&M costs of Block 7 during its lifetime.

In order to calculate the fixed O&M costs which remain the same during the whole life-time, we need to multiply the cost of one kW with the total installed capacity, which is 450,000 kW for the Block 7. Since we are looking for the annual costs, by multiplying 3 €/kW/month with 12, we get the amount of 36 €/kW/year. So the total annual fixed O&M costs for Block 7 amount to: 36 €/kW/year x 450,000 kW = 16,200,000 €/year.

The annual variable O&M costs can be calculated my multiplying the cost of one MWh with the annual expected net energy produced and injected into the transmission system stated in Table 37 in earlier sections of this paper. For the first year of operation, the total net energy production amounts to 2,550 GWh or 2,550,420 MWh. So the total variable O&M costs at the end of first year of operation of Block 7 amount to: 4.7 €/MWh x

2,550,420 MWh = 11,986,974 €. The variable costs for the remaining years can be easily calculated in the same way, by multiplying the cost of 1 MWh, i.e. 4.7 €/MWh with the respective annual electricity produced. Table 39 displays the results of all these calculations for each year of operation of "Block 7 Tuzla".

Table 39

O&M Costs of "Block 7 Tuzla"

Year	Fixed O&M costs	Variable O&M costs	Total O&M costs
	(€)	(€)	(€)
1	16,200,000	11,986,974	28,186,974
2	16,200,000	12,259,433	28,459,433
3	16,200,000	13,621,587	29,821,587
4	16,200,000	13,621,587	29,821,587
5	16,200,000	13,621,587	29,821,587
6	16,200,000	13,621,587	29,821,587
7	16,200,000	13,621,587	29,821,587
8	16,200,000	13,621,587	29,821,587
9	16,200,000	13,621,587	29,821,587
10	16,200,000	13,621,587	29,821,587
11	16,200,000	13,621,587	29,821,587
12	16,200,000	13,621,587	29,821,587
13	16,200,000	13,621,587	29,821,587
14	16,200,000	13,621,587	29,821,587
15	16,200,000	13,621,587	29,821,587
16	16,200,000	13,621,587	29,821,587
17	16,200,000	13,621,587	29,821,587
18	16,200,000	13,621,587	29,821,587
19	16,200,000	13,621,587	29,821,587
20	16,200,000	13,621,587	29,821,587
21	16,200,000	13,621,587	29,821,587
22	16,200,000	13,621,587	29,821,587
23	16,200,000	13,621,587	29,821,587
24	16,200,000	13,621,587	29,821,587
25	16,200,000	13,621,587	29,821,587

Note. Data are personal calculations.

5.3.2.4 Calculation of the Profitability Indicators

As there are two possible financing options shown earlier in Table 36, it was necessary to determine which credit option would be more profitable for the project bearer JP Elektroprivreda BiH. Table 40 displays the results of the NPV and IRR analysis for both options, made with the help of Fractal Software. The equity cash flow of only the more profitable scenario will be shown subsequently, followed with the calculation of the LCOE again.

Table 40

Results of the Analysis of Financial Viability of the Construction of "Block 7 Tuzla"

Financing model	Investment value	NPV	IRR
(credit type)	(€)	(€)	(%)
A. PBC	785,650,000	96,219,029	17.76
B. BC	835,000,000	-85,568,560	6.40

Note. Personal calculations conducted in Fractal Software.

If we observe the calculated IRR values shown in Table 40, it can be concluded that the construction project of "Block 7 Tuzla" is only profitable in the scenario A, i.e. financing model with the PBC Credit, whose total investment value is around 785 million EUR with a fixed interest rate of 2%, a five-year delay on loan repayment and a repayment period of 15 years (see Table 36). The positive NPV of 96,219,029 € and the IRR of 17.76% which is higher than the discount rate of 10% both confirm the profitability of the project when being financed by the PBC credit. However, the analysis of the project's profitability when being financed by the option B, i.e. BC credit, shows that the both NPV and IRR in this case are extremely unfavorable. The NPV is strictly negative while the IRR of 6.40% is much smaller than the 10% discount rate. These results are due to the higher total investment cost of around 835 million EUR and a shorter loan repayment period, i.e. 10 instead of 15 years, so the investment by choosing the financing model B should definitely not be undertaken since there is no positive return on the investment during the lifetime of the project.

It can be concluded that the construction of "Block 7 Tuzla" is profitable only in the scenario A, with the PBC credit and should be accepted since in this case, the project showed the acceptable values of both of these profitability indicators. Since the BC credit option showed strictly unfavorable results, the remaining parts of analysis was done only for the financing scenario A. Table 41 displays the equity cash flow of the “Block 7 Tuzla” under the conditions of the PBC credit.

Table 41

Equity Cash Flow of “Block 7 Tuzla”

Year	Gross profit	Net profit	Discounted	Cumulative net profit	Payback time
	(€)	(€)	(€)	(€)	(Year)
0	-117,847,512	-117,847,512	-117,847,512	-117,847,500	
1	27,106,167	23,085,742	20,987,038	-96,860,474	
2	26,089,081	22,093,132	18,258,787	-78,601,687	
3	25,059,789	21,087,993	15,843,721	-62,757,966	
4	24,018,146	20,070,163	13,708,191	-49,049,775	
5	22,964,004	19,039,475	11,822,016	-37,227,759	
6	21,897,212	17,995,764	10,158,139	-27,069,619	
7	20,817,618	16,938,859	8,692,313	-18,377,306	
8	19,725,069	15,868,589	7,402,814	-10,974,492	
9	18,619,410	14,784,780	6,270,190	-4,704,302	
10	17,500,482	13,687,256	5,277,030	572,728	10
11	16,368,128	12,575,838	4,407,754	4,980,482	
12	15,222,185	11,450,344	3,648,432	8,628,915	
13	14,062,491	10,310,591	2,986,611	11,615,526	
14	12,888,881	9,156,393	2,411,164	14,026,690	
15	11,701,187	7,987,561	1,912,159	15,938,849	
16	62,471,291	58,775,954	12,791,360	28,730,209	
17	61,254,922	57,681,221	11,411,922	40,142,131	
18	60,023,956	56,573,352	10,175,215	50,317,345	
19	58,778,219	55,452,188	9,066,876	59,384,221	
20	57,517,532	54,317,571	8,073,961	67,458,182	
21	56,241,718	53,169,338	7,184,803	74,642,985	
22	54,950,594	52,007,326	6,388,891	81,031,875	
23	53,643,976	50,831,370	5,676,754	86,708,629	
24	52,321,679	49,641,302	5,039,863	91,748,492	
25	50,983,514	48,436,954	4,470,537	96,219,029	

Note. Personal calculations conducted in Fractal Software.

As we can see from Table 41, the payback time under the financing scenario with the PBC credit is 10 years, after which significant net profit will be accumulated until the end of the lifetime of the power plant. Figure 26 illustrates the trend in cumulative equity cash flow of “Block 7 Tuzla” project during its entire lifetime of 25 years.

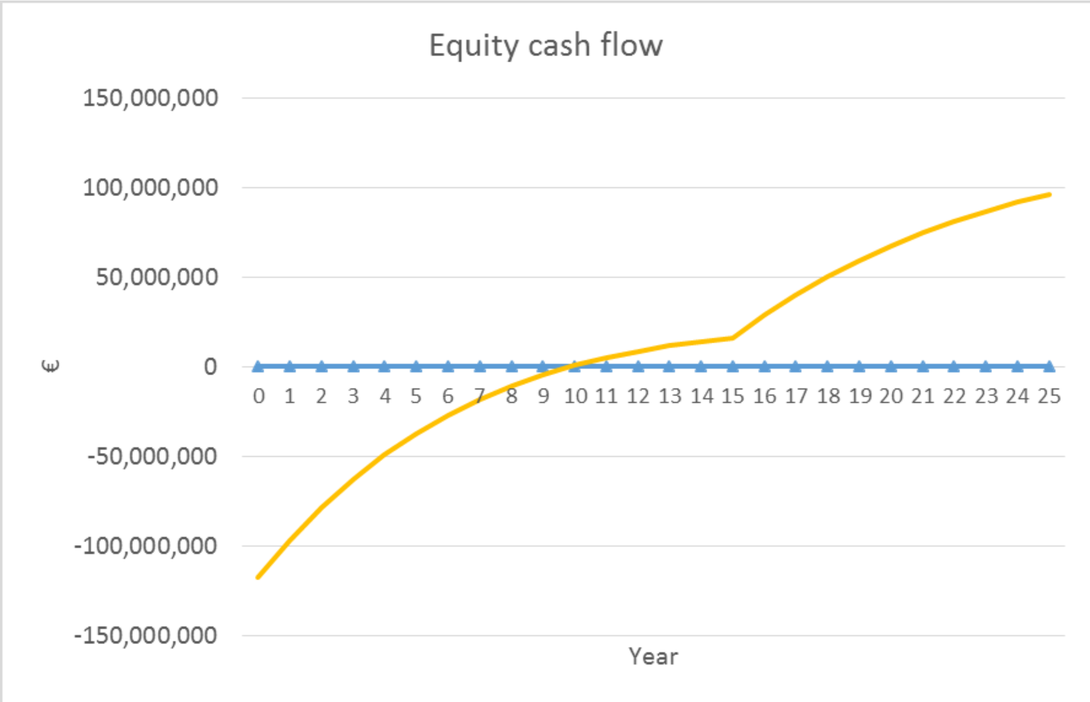

Figure 26. Graphical Presentation of the Equity Cash Flow during the Lifetime of “Block 7 Tuzla”.

This figure shows the trend in the movement of the equity cash flow during the period of 25 years of operation of the “Block 7 Tuzla”. The X-axis represents time period expressed in years, and the Y-axis represents the cash flow expressed in Euros.

Figure 26 shows that the cumulative net profit goes from the initial negative to a positive value in the tenth year of operation, which allows a significant accumulation of profits by the end of lifetime of the power plant. Compared to the WF “Mesihovina” and especially PV power plant “Kalesija”, “Block 7 Tuzla” generates the much higher cumulative net profit and it is obvious that it is an investment of much bigger scope than the other two related to renewable energy.

Even a quick and cursory analysis of the calculated indicators from Table 41 and Figure 26 shows that the project would timely secure the return on investment and obtain significant profits until the end of the lifetime of the Block 7 production unit. At the same time, the scenario A with the PBC credit could ensure sufficient financial resources to cover the decommissioning costs of Block 7 at the end of its lifetime, or even use those resources for an extension of the life span (additional 10 to 15 years) with a possible revitalization of Block 7 at the expiration of the originally planned lifespan of 25 years.

It is also worth noting that all the calculations made or presented in this case study of “Block 7 Tuzla” take into account the availability of significant domestic coal resources at competitive prices on the coal market, thus securing some resistance to significant shocks of coal price fluctuations on the world market during the entire lifetime of “Block 7 Tuzla”.

To finalize the profitability analysis of “Block 7 Tuzla” project, we will need to calculate the LCOE again, as it was the case with the PV power plant “Kalesija” and WF “Mesihovina”, but with a minor difference now. Unlike the LCOE calculation of the two power plants based on renewable energy, where the simplified LCOE equation was used, the LCOE of a typical coal-fired power plant can only be correctly calculated with the full LCOE equation that, besides the initial investment costs and O&M costs, in addition takes into account the fuel costs as well. These fuel costs do not exist in power plants based on renewable energy which is their great advantage, and when it comes to coal-fired power plants, the fuel costs refer to all the costs related to coal, as a primary fuel source for energy production.

Equation 1, presented in section 4.1 of this paper, is the full equation used in the following calculations of the LCOE of “Block 7 Tuzla”. Table 42 provides an overview of the input data used to calculate the LCOE using *Equation 1*, where the new component (in comparison to calculations for the PV power plant and WF) Fuel costs are marked as F_t. The values regarding the sums of annual total costs, annual fuel costs and annual electricity output are presented in the subsequent tables 43 and 44. It is also important to note that the LCOE for “Block 7 Tuzla” will only be calculated for the investment option A, since the PBC credit proved to be the only profitable investment solution.

Table 42

Input Data for the LCOE Calculation of "Block 7 Tuzla"

Component	Unit	Value	Source
Investment expenditure (I_t)	(€)	785,650,000	Table 36
Annual total cost (A_t), sum of A_t after 25 years	(€/year t)	268,079,980	Table 43
Annual fuel cost (F_t) sum of F_t after 25 years	(€/year t)	510,329,493	Table 43
Electricity output (E_t), sum of E_t after 25 years	(kWh/year)	25,751,474,763	Table 44
Discount rate (r)	(%)	10	Table 36
Lifetime (n)	(years)	25	Table 35
Year of lifetime (t)	(1,2,…,25)	1,2,…,25	Table 35

Note.

Generally, in order to calculate the annual fuel costs, it is necessary to know the three components: total annual produced electricity, the specific heat rate and the fuel price. The specific heat rate is the amount of energy that needs to be used in order to produce 1 kWh of electricity. The measure is usually expressed in kJ/kWh (kilojoule per kilowatt hour) and it depends on the type of coal used in the energy production. In the case of "Block 7 Tuzla", the power plant is supposed to operate entirely by using lignite as the primary energy source. According to Granić et al. (2008), the specific heat rate of lignite for "Block 7 Tuzla" amounts to 8,511 kJ/kWh, while the fuel price is 2.4 €/GJ (EUR per gigajoule) or converted 0.0000024 €/kJ (p. 30). By multiplying the heat rate with the total electricity produced in the first year of operation of Block 7, and expressed in kWh, we get the value of 21,706,624,620,000 kJ. This is the total amount of energy that needs to be used in order to produce the total estimated amount of electricity in the first year. Now the total fuel cost in first year is easily calculated by multiplying this number with the price of 0.0000024 €/kJ, so the total fuel cost in the first year of operation amounts to 52,095,899 €. In the same way, the annual fuel costs for the remaining 24 years of life-time of Block 7 are calculated, but with an important note, that there is an assumed coal price growth of 1% annually during the whole lifetime of "Block 7 Tuzla". This assumption was made on the basis of the coal price projections made by the project bearer J.P. Elektroprivreda BiH (2014, p. 27). Table 43 displays the results of the calculations of all the annual undiscounted and discounted fuel costs, in addition to the total annual O&M costs, undiscounted and discounted as well. The undiscounted values of O&M costs were calculated earlier and displayed in Table 39.

Table 43

Annual O&M and Fuel Costs of "Block 7"

Year	Undiscounted total annual cost (A_t)	Discount factor [$(1+r)^t$]	Discounted total annual cost [$A_t / (1+r)^t$]	Undiscounted fuel cost (F_t)	Discount factor [$(1+r)^t$]	Discounted fuel cost [$F_t / (1+r)^t$]
	(€)		(€)	(€)		(€)
1	28,186,974	1.1	25,624,522	52,095,899	1.1	47,359,908
2	28,459,433	1.2	23,520,193	52,616,858	1.2	43,485,007
3	29,821,587	1.3	22,405,400	53,143,027	1.3	39,927,142
4	29,821,587	1.5	20,368,545	53,674,457	1.5	36,660,376
5	29,821,587	1.6	18,516,859	54,211,201	1.6	33,660,891
6	29,821,587	1.8	16,833,508	54,753,313	1.8	30,906,818
7	29,821,587	1.9	15,303,189	55,300,847	1.9	28,378,078
8	29,821,587	2.1	13,911,990	55,853,855	2.1	26,056,236
9	29,821,587	2.4	12,647,264	56,412,394	2.4	23,924,362
10	29,821,587	2.6	11,497,513	56,976,518	2.6	21,966,914
11	29,821,587	2.9	10,452,284	57,546,283	2.9	20,169,621
12	29,821,587	3.1	9,502,077	58,121,746	3.1	18,519,379
13	29,821,587	3.5	8,638,252	58,702,963	3.5	17,004,157
14	29,821,587	3.8	7,852,956	59,289,993	3.8	15,612,908
15	29,821,587	4.2	7,139,051	59,882,893	4.2	14,335,488
16	29,821,587	4.6	6,490,046	60,481,721	4.6	13,162,585
17	29,821,587	5.1	5,960,042	61,086,539	5.1	12,085,646
18	29,821,587	5.6	5,363,675	61,697,404	5.6	11,096,820
19	29,821,587	6.1	4,876,068	62,314,378	6.1	10,188,899
20	29,821,587	6.7	4,432,789	62,937,522	6.7	9,355,262
21	29,821,587	7.4	4,029,808	63,566,897	7.4	8,589,831
22	29,821,587	8.1	3,663,462	64,202,566	8.1	7,887,027
23	29,821,587	9.0	3,330,420	64,844,592	9.0	7,241,725
24	29,821,587	9.8	3,027,654	65,493,038	9.8	6,649,220
25	29,821,587	10.8	2,752,413	66,147,968	10.8	6,105,193
Total			**268,079,980**			**510,329,493**

Note. Data are personal calculations.

When presenting the total annual costs related to coal-fired power plants in general, it is important to note that there is also one additional type of costs: the costs of CO_2 emissions. However, the reason why these costs were not included in these calculations is that in BiH, no CO_2 trading system has been established yet. But it is certain that the costs that will surely emerge after the establishment of such trading system will further increase the costs of electricity production in coal-fired power plants in BiH, so the final LCOE value would be higher and less favorable than the one calculated without the CO_2 emission costs. In any case, it is necessary to keep in mind that the possible increase in CO_2 emission costs for example in over 10 €/tCO_2 can seriously undermine the financial viability of “Block 7 Tuzla” project.

The final component for the calculation of LCOE is again the annual electricity production and Table 44 displays the undiscounted and discounted values of this component. Because of the better data visibility and because of the emergence of the fuel costs by “Block 7 Tuzla”, the data on annual electricity produced is displayed in the separate table from the total annual costs as it was the case with both PV power plant “Kalesija” and WF “Mesihovina”.

Table 44

Annual Electricity Output of "Block 7 Tuzla"

Year	Undiscounted total electricity produced (E_t)	Discount factor [$(1+r)^t$]	Discounted total electricity produced [$E_t / (1+r)^t$]
	(kWh)		(kWh)
1	2,550,420,000	1.1	2,318,563,636
2	2,608,390,000	1.2	2,155,694,215
3	2,898,210,000	1.3	2,177,468,069
4	2,898,210,000	1.5	1,979,516,426
5	2,898,210,000	1.6	1,799,560,388
6	2,898,210,000	1.8	1,635,963,989
7	2,898,210,000	1.9	1,487,239,990
8	2,898,210,000	2.1	1,352,036,354
9	2,898,210,000	2.4	1,229,123,959
10	2,898,210,000	2.6	1,117,385,417
11	2,898,210,000	2.9	1,015,804,924
12	2,898,210,000	3.1	923,459,022
13	2,898,210,000	3.5	839,508,202
14	2,898,210,000	3.8	763,189,275
15	2,898,210,000	4.2	693,808,431
16	2,898,210,000	4.6	630,734,938
17	2,898,210,000	5.1	573,395,398
18	2,898,210,000	5.6	521,268,544
19	2,898,210,000	6.1	473,880,494
20	2,898,210,000	6.7	430,800,449
21	2,898,210,000	7.4	391,636,772
22	2,898,210,000	8.1	356,033,429
23	2,898,210,000	9.0	323,666,754
24	2,898,210,000	9.8	294,242,503
25	2,898,210,000	10.8	267,493,185
Total			**25,751,474,763**

Note. Data are personal calculations.

Now it is possible to calculate the final LCOE value of "Block 7 Tuzla". The numerator of *Equation 1* is the sum of the initial investment, total O&M costs and total fuel costs for the entire lifetime of the power plant. The total sum of these three components is then divided by the total sum of electricity produced during the entire lifetime. Table 45 displays the procedure and the final value of LCOE for "Block 7 Tuzla".

Table 45

Calculation of the LCOE of "Block 7 Tuzla"

Component A: investment expenditure (I_0)	Component B: I_0 + 25 years total of [$A_t / (1+r)^t$] + 25 years total of [$F_t / (1+r)^t$]	Component C: 25 years total of [$E_t / (1+r)^t$]	LCOE (B / C)
(€)	(€)	(kWh)	(€ / kWh)
785,650,000	1,564,059,472	25,751,474,763	0.0607

Note. Data are personal calculations.

The calculated LCOE value of 0.0607 €/kWh is comparable to the calculated LCOE values of other power plants in Europe that use lignite as a primary energy source. As displayed in Figure 13, Section 3.5, earlier in this paper, LCOE for lignite-fired power plants in the EU ranges from 2.9 to 8.4 €ct/kWh, while the calculated LCOE of "Block 7 Tuzla" amounts to 6.07 €ct/kWh. The comparison of "Block 7 Tuzla" LCOE with the LCOE values of the PV power plant "Kalesija" and WF "Mesihovina" will be elaborated in Chapter 7.

Table 46 summarizes the profitability analysis of the "Block 7 Tuzla" project by providing an overview of the key calculated profitability indicators, i.e. NPV, IRR and LCOE.

Table 46

Final Display of the NPV, IRR and LCOE of "Block 7 Tuzla"

Profitability measure	Unit	Value
NPV	(€)	96,219,029
IRR	(%)	17.76
LCOE	(€ / kWh)	0.0607

Note. Since the financing scenario A proved to be the only financing model by which the construction of the Block 7 would be profitable, this table lists only the profitability indicators measured under the circumstances of the scenario A, i.e. PBC Credit financing.

All the calculated measures indicate that the investment in "Block 7 Tuzla" is profitable and should be undertaken. The direct comparison to the other two, earlier in this paper analyzed power plants, will be conducted in Chapter 7 as the part of the concluding considerations on the electricity mix in BiH.

6. Factors Influencing the Profitability of Electricity Production in Photovoltaic, Wind and Coal-Fired Power Plants

In the previous chapter, case study consisted of the feasibility analysis of construction of the two power plants based on renewable sources in BiH, namely PV power plant “Kalesija” and WF “Mesihovina”, as well as the cost-effectiveness of the construction of a thermal power plant based on conventional sources (coal), i.e. “Block 7 Tuzla”.

Each of the power plants analyzed in the case study in Chapter 5, has its own specific factors whose changes may, to a lesser or greater extent, affect the overall economic and financial indicators of these projects. In addition to the specific factors related to the type of electricity production technology, there are some common sensitive factors such as the discount rate, whose variation can have a strong impact on the cost of capital and consequently on the profitability of the investment. Also, changes in the prices of fuel used in electricity production by some conventional technologies as well as the movement of electricity prices in the open market are the most common and most important factors that could jeopardize the economic and financial sustainability of a power plant construction project.

This chapter covers how the profitability results of each of the three analyzed power plants in this paper react to the changes of the most important sensitivity factors. Section 6.1 elaborates the sensitivity of the PV Power Plant “Kalesija”, WF “Mesihovina” and “Block 7 Tuzla” to such changes. In addition section 6.2 covers the external costs of these three power plants.

6.1 Sensitivity to Changes in Key Parameters Influencing the Electricity Production in PV Power Plant “Kalesija”, WF “Mesihovina” and “Block 7 Tuzla”

The main factors that were subject to analysis in this chapter and that influence the profitability of the three power plants from the case study are the discount rate, the number of operating hours and, additionally in the case of “Block 7 Tuzla”, the price of coal. The discount rate can be understood as a measure of the cost of capital. The higher the rate, the smaller the potential return on investment, and vice-versa. Even small changes in the discount rate can have a significant impact on the potential returns and the overall profitability of the project. This section will show how the profitability of each of the three power plants reacts to 4% changes in the discount rate in both directions, when compared to the initial value. The initial discount rate for all three power plants that was used in the case study in Chapter 5 was 10%, so the two experiment cases are for the discount rates of 6% and 14%.

Another factor whose impact on the profitability of power plants was analyzed was the number of operating hours expressed as the capacitance factor which will be further elaborated in section 6.1.1. The number of operating hours is a greater concern for the power plants based on renewable energy, since their capacitance factor is already low, much lower than those of conventional power plants, so a further drop in the number of operating hours can make a project completely unprofitable. This chapter will present a sensitivity analysis of how the three power plants react to changes in the number of operating hours of the respective power plant in the amount of 10% in both directions.

The final factor that is related only to “Block 7 Tuzla” is the price of coal. Since coal is the primary energy fuel for the conventional thermal power plants such as “Block 7 Tuzla”, it is obvious that the profitability of such production facilities highly depends on the market price of coal. This chapter will analyze how the profitability indicators of “Block 7 Tuzla” change if the prices of coal increase or fall for 12%.

With respect to the above mentioned influencing factors, sections 6.1.1, 6.1.2 and 6.1.3 will present the results of the analysis of the impact of these parameters on the profitability of the PV power plant “Kalesija”, WF “Mesihovina” and “Block 7 Tuzla” respectively.

6.1.1 Parameters Influencing the Profitability of the PV Power Plant “Kalesija”

When it comes to PV power plants and generally power plants based on renewable energy, to some extent, the relative lack of external costs and no fuel costs can compensate for the higher volatility in the electricity production due to high dependence on climate conditions. In addition, if we assume that, with at least some certainty, we can predict the potential of solar energy at the site of the PV power plant, then we can narrow the sensitivity of the profitability of the project in PV power plant “Kalesija” to changes in two important factors: cost of capital and a volatility in the number of operating hours of a power plant.

An easy way to find the cost of capital could be trough the discount rate. If we make changes in the discount rate, just for the purpose of experiment, we could see how even small changes in this rate can have significant impact on the profitability measures like NPV, IRR or LCOE. Bigger changes in the discount rate can seriously jeopardize the overall profitability of the project.

Figure 27 demonstrates how the equity cash flow of the PV power plant “Kalesija” would react if the initial and actual discount rate of 10% would drop to 6% or rise to 14%. The curves were made on the basis of the calculations made in Fractal Software in the same way as it was done in the actual analysis of the PV power plant “Kalesija” in Chapter 5. The only alteration was changing the discount rate of 10% into 6 and 14% respectively, while all the other factors of this project were left the same as during the case study.

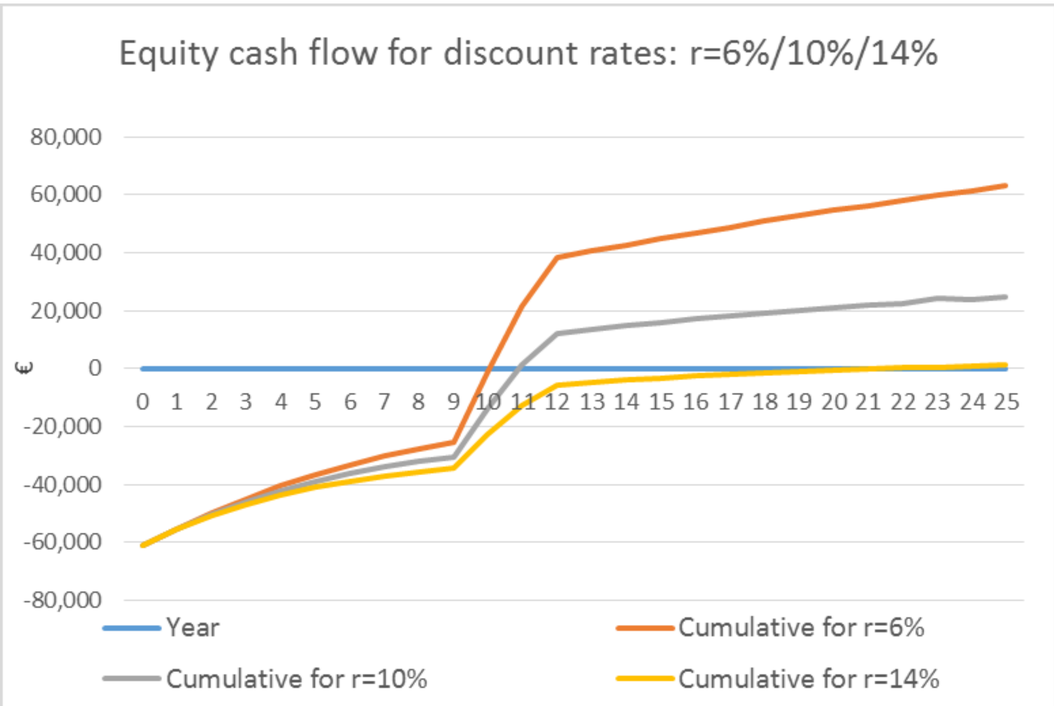

Figure 27. Impact of the Discount Rate on Equity Cash Flow of the PV Power Plant “Kalesija”

This figure illustrates how the cumulative equity cash flow of the PV power plant "Kalesija" changes if the initial discount rate of 10% falls to 6% or increases to 14%. Figure 27 shows that the application of the discount rate of 6% generates the higher NPV of 63,024 € compared to the NPV of 24,698 € for a base discount rate of 10% while the equity payback time remains the same. In the other scenario, if the discount rate would be 14%, the project would generate an extremely low NPV of only 1,139 €, while increasing equity payback time to very bad 22 years, just 3 years before the end of the lifecycle, making the investment almost worthless.

Table 47 displays how the exact values of the NPV, IRR and equity payback time changed in comparison to the values calculated in Chapter 5, as the result of the above mentioned changes in the discount rate.

Table 47

Sensitivity of the Profitability Indicators of the PV Power Plant "Kalesija" to the Changes in the Discount Rate

Measure	Unit	For the discount rate: r=6%	For the discount rate: r=10%	For the discount rate: r=14%
NPV	(€)	63,024	24,698	1,139
IRR	(%)	14.25	14.25	14.25
Equity payback time	(years)	11	11	22
Benefit-cost ratio		2.03	1.40	1.02

Note. Data are personal calculations conducted in Fractal Software.

Based on the results in Table 47, we can conclude that a lower discount rate, which would actually mean a lower cost of capital, generates a higher NPV and ensures a shorter time of return on equity, making the investment more cost-effective than in the case of higher discount rates. The change in the discount rate in the amount of 4% produces an enormous change in the NPV and equity payback time, so the clearly profitable investment in the PV power plant "Kalesija" when the discount rate is at 10%, would be basically worthless if the discount rate increased by just 4%.

Apart from the discount rate, another factor that could seriously affect the profitability of an investment is the amount of produced electricity in ratio to the maximum possible electricity output at the full installed capacity of a power plant. Or simply, it could be described as the degree of utilization of the total installed power. This measure is usually named as the capacity factor. Ibarra-Berastegi (2018) stated that the capacity factor can easily be calculated with the following equation (p. 21).

$$\text{CapF} = \frac{Actual\ annual\ electricity\ output\ (kWh)}{Installed\ capacity\ (kW) x\ Total\ number\ of\ hours\ in\ one\ year\ (h)} \qquad (6)$$

CapF = Capacity Factor

Total number of hours in one year = 8760 h

If we know that the projected average annual electricity output of the PV power plant "Kalesija" amounts to 130,050 kWh, while the total installed capacity is 123 kW, then the capacity factor for this amount of annually produced electricity has the value of 0.1207 or 12.07%. When calculating the number of operating hours out of these values, the capacity factor of 12.07% means that the number of actual operating hours in one year was 1057 h. The capacity factor of 12.07% is the actually projected annual degree of utilization of the installed capacity of the PV power plant "Kalesija" when it operates for 1057 h per year. Now it is reasonable to assume that the maximum operating hours during one year should not deviate for more than 10% in either direction, so it would be interesting to see what happens with the equity cash flow if the number of operating hours drops or increases for 10%. Table 48 displays the effect of these changes on the capacity factor and the total produced electricity.

Table 48

Effects of the Changes in Operating Hours on the Capacity Factor and Electricity Output of the PV Power Plant "Kalesija"

Component	Unit	By 951 operating hours (-10%)	By 1057 operating hours (base value)	By 1163 operating hours (+10%)
Capacity factor	(%)	10.86	12.07	13.28
Annual electricity output	(kWh)	117,010	130,050	143,090

Note. Data are personal calculations.

Figure 28 illustrates how the changes in the number of operating hours affect the equity cash flow of the PV power plant "Kalesija".

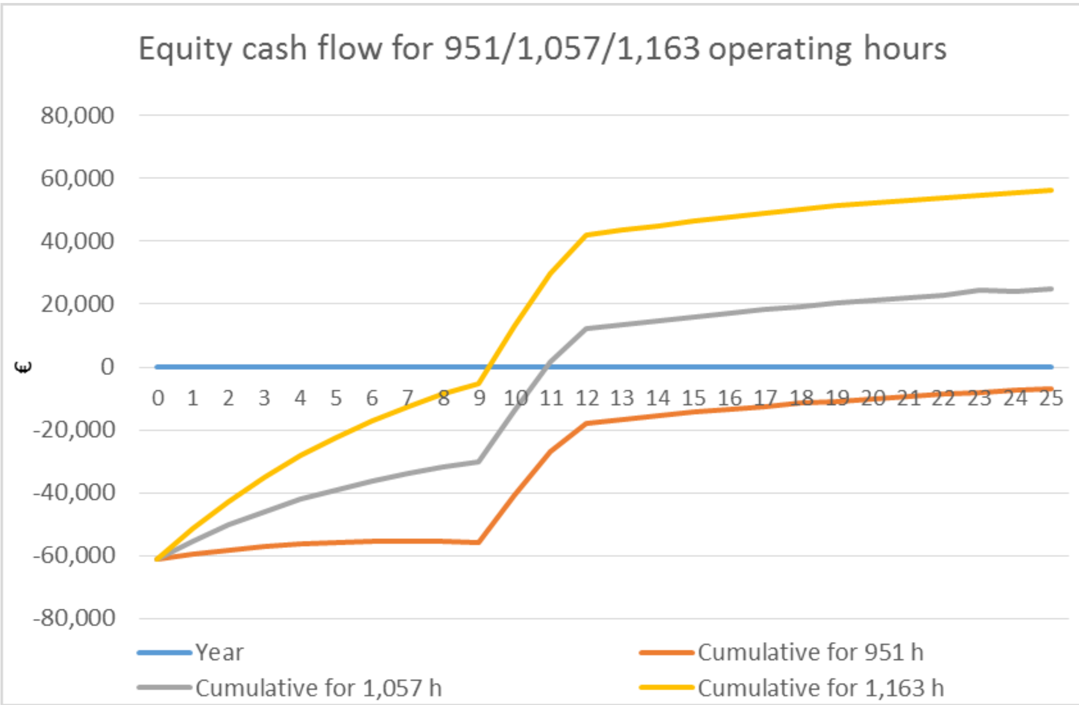

Figure 28. Impact of the Number of Operating Hours on Equity Cash Flow of the PV Power Plant "Kalesija"

This figure illustrates how the equity cash flow curves change when the number of operating hours drops to 951 h (-10% of the base value) or increases to 1163 h (+10% of the base value).

Figure 28 shows that, for the capacity factor of 10.86%, which corresponds to 951 hours of operation, the project is not profitable, because the cumulative equity cash flow is negative for the entire lifetime of the PV power plant “Kalesija”. The drop of just 10% in the number of operating hours would make an investment completely unprofitable and the project would have to be rejected. However, if the number of operating hours would increase by 10%, the equity payback time would be shortened for one year, while the NPV value would strongly increase. Table 49 provides the results of the calculations made in Fractal Software, for each of the two alterations in the number of annual operating hours, as well as the base values calculated in Chapter 5 for the purpose of comparison.

Table 49

Sensitivity of the Profitability Indicators of the PV Power Plant “Kalesija” to the Changes in the Number of Operating Hours

Measure	Unit	951 h (CapF=10.86%)	1057 h (CapF=12.07%)	1163 h (CapF=13.28%)
NPV	(€)	-6,952	24,698	56,344
IRR	(%)	8.86	14.25	20.08
Equity payback time	(years)	0	11	10
Benefit-cost ratio		0.89	1.40	1.92

Note. Data are personal calculations conducted in Fractal software.

It is obvious that the 10% drop in the number of operating hours would produce the negative NPV value of -6,952 € and would make the investment unprofitable. If the operating hours would increase for 10%, then the NPV would be more than the double of the actual projected amount, with even more favorable benefit-cost ratio and shortened return on investment time.

6.1.2 Parameters Influencing the Profitability of the WF "Mesihovina"

The profitability sensitivity to the changes in the discount rate and the number of operating hours can be done in the same way for the WF "Mesihovina". Although WF "Mesihovina" does have external costs in addition, these will be elaborated later in Section 6.2 of this chapter.

In comparison to the PV power plant "Kalesija", WF "Mesihovina" is slightly less sensitive to discount rate changes in terms that the change of 4% in either direction will not make the investment almost unprofitable as it was the case with the PV power plant. Although the higher discount rate produces lower cumulative equity cash flow, it is still strongly positive and the equity payback time does not change that much. Figure 29 illustrates how the equity cash flow behaves for the discount rates of 6, 10 and 14%.

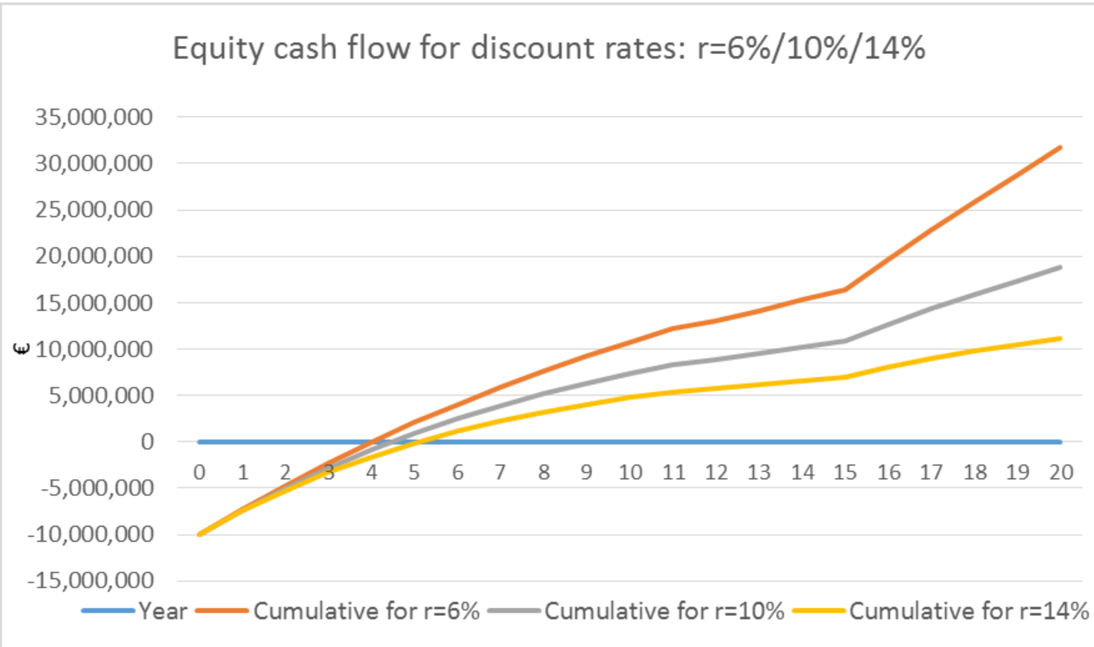

Figure 29. Impact of the Discount Rate on Equity Cash Flow of the WF "Mesihovina"
This figure illustrates how the cumulative equity cash flow of the WF "Mesihovina" changes if the initial discount rate of 10% falls to 6% or increases to 14%.

As illustrated in Figure 29, the change in the discount rate to 6% and 14% compared to the base discount rate of 10% will not question the feasibility of investing in the construction of the WF "Mesihovina", since all three cases produce a positive NPV and IRR higher than the respective discount rate. Table 50 displays the results of the calculations when only the discount rate was changed, while all the other factors used for the analysis in Chapter 5 were kept the same.

Table 50

Sensitivity of the Profitability Indicators of the WF "Mesihovina" to the Changes in the Discount Rate

Measure	Unit	For the discount rate: r=6%	For the discount rate: r=10%	For the discount rate: r=14%
NPV	(€)	31,694,781	18,753,693	11,164,838
IRR	(%)	29.00	29.00	29.00
Equity payback time	(years)	5	5	6
Benefit-cost ratio		4.17	2.87	2.12

Note. Data are personal calculations conducted in Fractal software.

Table 50 shows that the equity payback time is similar in all three cases, but the benefit-cost ratio changes because the higher value of the discount rate generates a lower ratio due to the more expensive cost of capital. Naturally, as a consequence, the NPV values also change. The higher the cost of capital, the lower the NPV and vice-versa. The IRR remains the same in each case. It can be concluded that all three cases confirm the profitability of the project WF "Mesihovina", just in different benefit-cost ratios, where the projects with lower discount rate are more profitable than the ones with a higher one.

The other parameter used for the sensitivity analysis, i.e. the capacity factor, when calculated with *Equation 6*, and taking the input values from Chapter 5, has the value of 33.49% which corresponds to total 2,934 annual operating hours. These values were taken as the base values for conducting the analysis of the deviations in the capacity factor, which in this case are set at ±20% of the base capacity factor. Table 51 displays the deviations of the annual produced electricity as a result of the change in the capacity factor, i.e. in the number of total annual operating hours of the WF „Mesihovina".

Table 51

Effects of the Changes in Operating Hours on the Capacity Factor and Electricity Output of the WF "Mesihovina"

Component	Unit	By 2,347 operating hours (-20%)	By 2,934 operating hours (base value)	By 3,608 operating hours (+20%)
Capacity factor	(%)	26.79	33.49	41.19
Annual electricity output	(kWh)	103,259,380	129,083,860	158,762,740

Note. Data are personal calculations.

The assumed deviations in the number of operating hours from the base value of 2,934 h are practically possible, since wind is a stochastic phenomenon with extremely variable intensity, speed and direction. Out of this reason the sensitivity was analyzed for 20% rather than the 10% deviations used in the analysis of the PV power plant "Kalesija". Figure 30 illustrates the trend in cumulative equity cash flow that resulted from these changes, as well as the initial equity cash flow with base values.

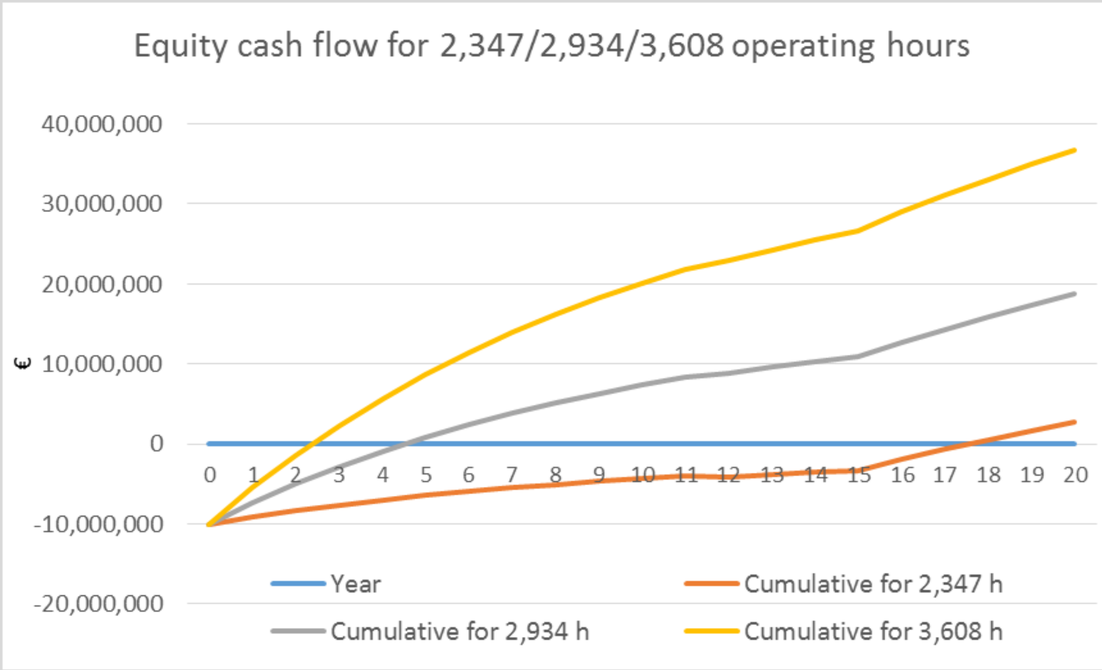

Figure 30. Impact of the Number of Operating Hours on Equity Cash Flow of the WF "Mesihovina".

This figure illustrates how the equity cash flow curves change when the number of operating hours drops to 2,347 h (-10% of the base value) or increases to 3,608 h (+10% of the base value).

Figure 30 shows that it is clear that in the case of operating hours, a drop of 20% causes a drastic fall in the total produced electricity which results in the investment being hardly profitable with the equity payback time only 2 years before the end of lifecycle of the power plant, making the investment not worthy of undertaking. On the other hand, an increase of 20% can almost double the cumulative equity cash flow in relation to the base values. Table 52 displays the exact values of NPV, IRR, equity payback time and benefit-cost ratio for these hypothetical scenarios.

Table 52

Sensitivity of the Profitability Indicators of the WF "Mesihovina" to the Changes in the Number of Operating Hours

Measure	Unit	2,347 h (CapF=26.79%)	2,934 h (CapF=33.49%)	3,608 h (CapF=41.19%)
NPV	(€)	2,706,434	18,753,693	36,726,266
IRR	(%)	12.40	29.00	49.41
Equity payback time	(years)	18	5	3
Benefit-cost ratio		1.27	2.87	4.67

Note. Data are personal calculations conducted in Fractal Software.

A 20% deviation in negative direction from the base capacity factor of 33.49% (2,934 h of annual operation) would lead to less annual electricity produced, which would result in an enormous reduction in NPV (from 18,753,693 € to 2,706,434 €) and a prolongation of the payback time from quite good 5 years to extremely unfavorable 18 years, just 2 years before the end of the lifetime of an average wind farm. The IRR of 12.40% would still be higher than the discount rate of 10%, however the benefit-cost ratio would suffer a serious drop. In the other case, if the number of operating hours would increase to 3,608 h from the initial 2,934 h, then the total electricity output would also increase, while the NPV would almost double in its value with the equity payback time shortened for further 2 years. The benefit-cost ratio and IRR would be extremely favorable as well.

Generally, apart from wind as a key factor affecting the number of hours of operation of a typical wind farm, the total number of operating hours per year can be significantly influenced by the wind turbines themselves as well, i.e. possible breakdowns, which can be common due to the location of the wind turbine in the climatic conditions and the speed of fault resolutions.

6.1.3 Parameters Influencing the Profitability of "Block 7 Tuzla"

Given that the 785,650,000 € worth investment in "Block 7 Tuzla" is much bigger than the investments in the two power plants analyzed earlier, the issue of capital cost is even more important in the process of assessing the viability of such investment. The analysis of the impact of the discount rate, as the expression of the cost of capital, on the profitability of the investment in "Block 7 Tuzla" was again based on the initial discount rate of 10%, while the change of 4% in both directions was used to analyze how the equity cash flow and profitability indicators would react. Figure 31 illustrates the cumulative equity cash flow during the entire 25 year lifetime of "Block 7 Tuzla", for the discount rates of 6, 10 and 14%.

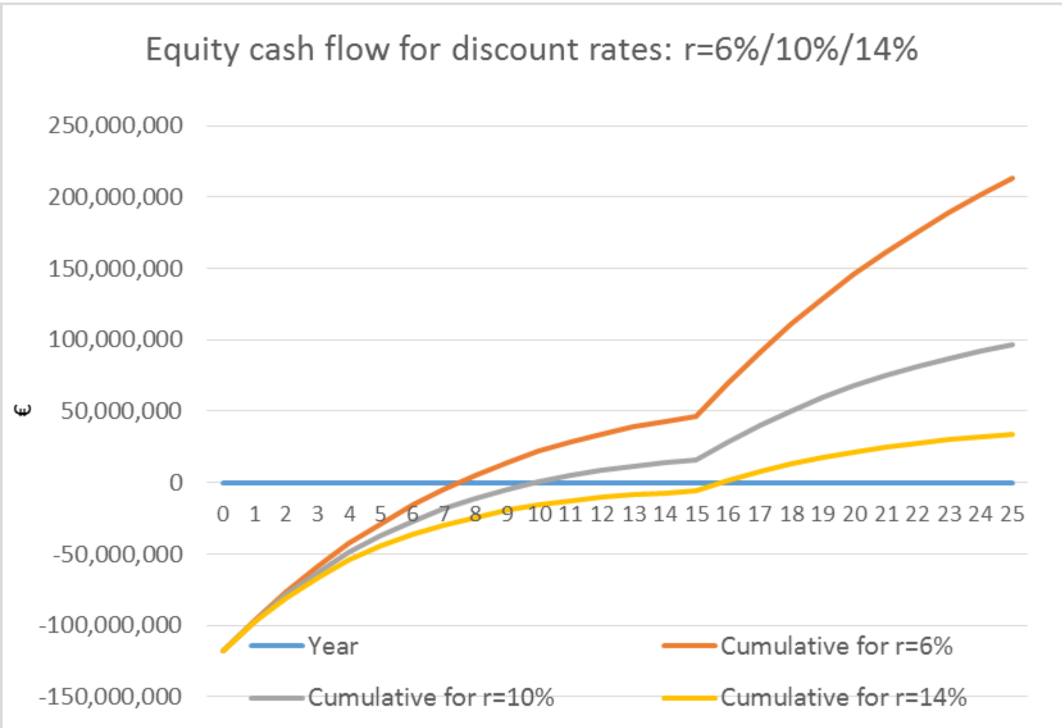

Figure 31. Impact of the Discount Rate on Equity Cash Flow of "Block 7 Tuzla"
This figure illustrates how the cumulative equity cash flow of "Block 7 Tuzla" changes if the initial discount rate of 10% falls to 6% or increases to 14%.

Figure 31 shows that the increase in the cost of capital, i.e. the increase of the discount rate from 10% to 14% would significantly prolong the equity payback time, from 10 to 16 years. The cumulative cash flow at the end of the lifetime would be smaller than in the case of 10% discount rate, but would still be positive. However, the fall in the discount rate from 10% to 6% would more than double the cumulative equity cash flow at the end of the lifetime, with a simultaneous equity payback time reduction from 10 to 8 years. Table 53 displays the calculated NPV, IRR, equity payback time and benefit-cost ratio for each of the three scenarios.

Table 53

Sensitivity of the Profitability Indicators of "Block 7 Tuzla" to the Changes in the Discount Rate

Measure	Unit	For the discount rate: r=6%	For the discount rate: r=10%	For the discount rate: r=14%
NPV	(€)	212,826,758	96,219,029	34,102,322
IRR	(%)	17.76	17.76	17.76
Equity payback time	(years)	8	10	16
Benefit-cost ratio		2.81	1.82	1.29

Note. Data are personal calculations conducted in Fractal Software.

The values of the profitability measures from Table 53 indicate that the project would still qualify as the financially viable in each case of the projected discount rates, but with considerably different benefit-cost ratios. Since the investment in "Block 7 Tuzla" is considered to be a huge investment from the perspective of a developing country such as BiH, even at the initial discount rate of 10%, the project would generate a huge NPV value, let alone the hypothetical scenario whit 6% discount rate that would, for the BiH standards, generate an enormous 212,826,758 €. Even the increase of the discount rate to 14% would still yield solid NPV of 34,102,322 €. The IRR remained for all three scenarios the same.

As with the other two analyzed power plants, the capacity factor may have a significant impact on the project's viability since the amount of produced electricity directly depends on the number of operating hours, besides other factors like the capacity of the power plant. The capacity factor in coal-fired power plants is understandably far greater than the capacity factor in power plants based on renewable energy sources, due to far less volatility in production. Although the number of operating hours does not depend on the natural, climate conditions like it was the case with the two power plants based on renewable energy, for the purpose of comparison, the 10% deviations from the initial 7,000 operating hours were nonetheless analyzed, though they are less likely to happen than in the two previous cases. Table 54 displays how the total annual electricity output changes if the number of operating hours of “Block 7 Tuzla” falls to 6,300 h or increases to 7,700 h annually.

Table 54

Effects of the Changes in Operating Hours on the Capacity Factor and Electricity Output of “Block 7 Tuzla”

Component	Unit	By 6,300 operating hours (-10%)	By 7,000 operating hours (base value)	By 7,700 operating hours (+10%)
Capacity factor	(%)	71.92	79.91	87.90
Annual electricity output	(kWh)	2,608,389,000	2,898,210,000	3,188,031,000

Note. Data are personal calculations.

As we can see from Table 54, when “Block 7 Tuzla” operates for 7,000 h annually, it produces 2,898,210,000 kWh of electricity, which means that the power plant works at the capacity of almost 80%, which in comparison to the 33% capacity factor of the WF “Mesihovina and just 12% capacity factor of the PV power plant “Kalesija” is enormously greater rate. This is one of the most common problems of power plants based on renewable energy and one of the reasons why the developing countries such as BiH are still heavily dependent on conventional coal-fired power plants and why they still consider new investments in such plants. The 10% increase in the number of operating hours would further increase the capacity factor to almost 88%, which would mean that “Block 7 Tuzla” would produce more than 3 billion kWh of electricity per annum. Of course, bigger electricity output would mean further increase in the cumulative equity cash flow. Figure 32 shows how the equity cash flow of “Block 7 Tuzla” would change if the number of operating hours would both drop and increase for 10%.

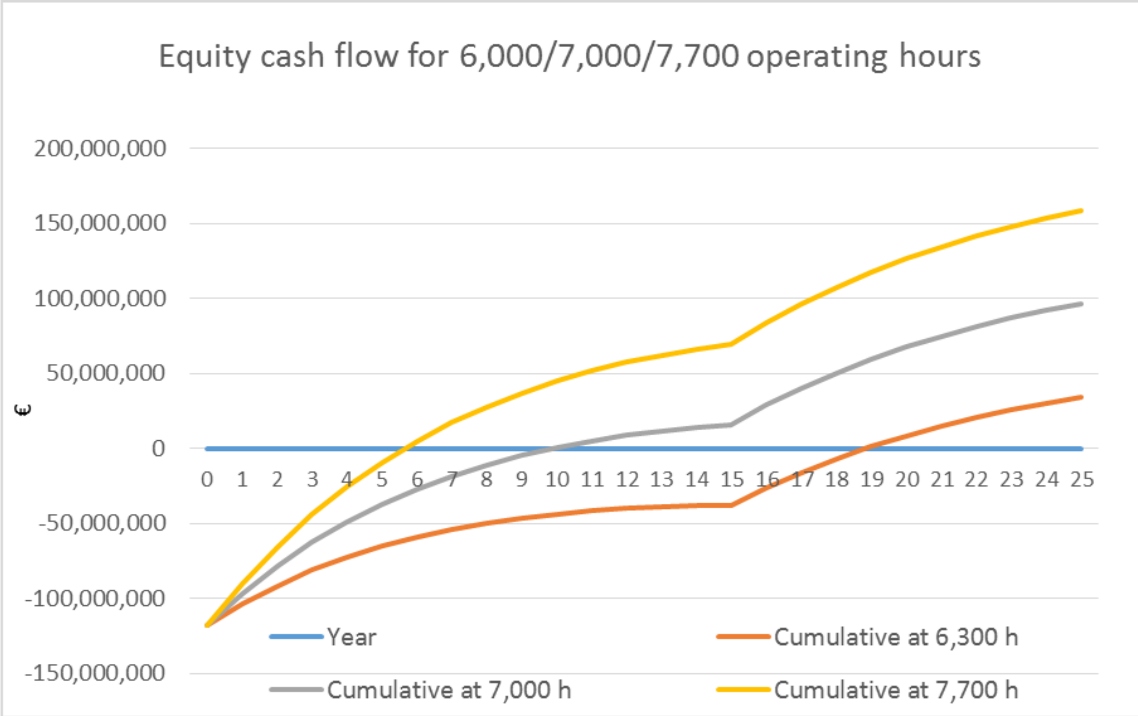

Figure 32. Impact of the Number of Operating Hours on Equity Cash Flow of "Block 7 Tuzla"

This figure illustrates how the equity cash flow curves change when the number of operating hours drops to 6,300 h (-10% of the base value) or increases to 7,700 h (+10% of the base value).

Figure 32 clearly shows that the influence of the number of operating hours, i.e. the capacity rate at which "Block 7 Tuzla" operates is a very important factor for assessing the sensitivity of this investment. The 10% reduction in the annual operating hours (6,300 h) in contrast to the projected 7,000 h, strongly reduces the cumulative equity cash flow and prolongs the time of return on capital from the initial 10 to 19 years, just six years before the end of the lifetime. Contrary to this, any increase in the number of hours of operation above the planned 7,000 hours would result in an increase in the cumulative equity cash flow, and the increase in the NPV, IRR and benefit cost ratio as well, while simultaneously reducing the time of return of the invested capital, which is initially after 10 years. If the number of operating hours would increase for 10%, the investment would be paid off already after 6 years. Table 55 displays the exact values of these measures in all three scenarios.

Table 55

Sensitivity of the Profitability Indicators of "Block 7 Tuzla" to the Changes in the Number of Operating Hours

Measure	Unit	6,300 h (CapF=71.92%)	7,000 h (CapF=79.91%)	7,700 h (CapF=87.90%)
NPV	(€)	34,127,595	96,219,029	158,310,463
IRR	(%)	12.57	17.76	23.54
Equity payback time	(years)	19	10	6
Benefit-cost ratio		1.29	1.82	2.34

Note. Data are personal calculations conducted in Fractal Software.

The changes in each of the profitability measures displayed in Table 55 are relatively big for each change in the capacity factor, which means that the change in the number of operating hours of just 10% would result in huge changes in expected returns on this investment. Naturally a 10% increase in the operating hours would yield the greatest benefits out of the three analyzed scenarios.

In contrast to the power plants based on renewable energy, the conventional coal-fired power plants in addition have one more extremely important source of costs, i.e. the price of fuel. As already mentioned in Chapter 5, "Block 7 Tuzla" uses lignite as the type of coal used as a primary energy source for electricity production and it's price amounts to 2.4 €/GJ. In calculations for the base scenario, the following data from Chapter 5 were used: total projected annual coal consumption in the production of 2,700,000 tons, coal price of 2.4 €/GJ, and the specific heat consumption of 8,511 kJ/kWh. With the purpose to gain an insight in the sensitivity of the profitability of "Block 7 Tuzla" to the changes in the coal price, two scenarios were analyzed: the one where the price of coal drops for 12% (2.11 €/GJ), and the other where the price of coal increases for 12% (2.69 €/GJ). Other costs, as well as their growth trend were kept at the same level as in the baseline scenario just for the more effective and credible analysis of the impact of the change in the price of coal itself. Figure 33 shows how the trends in cumulative equity cash flow change between the base scenario and two deviation scenarios resulting from the 12% increase and 12% decrease in coal price, relative to the baseline price of 2.4 €/GJ.

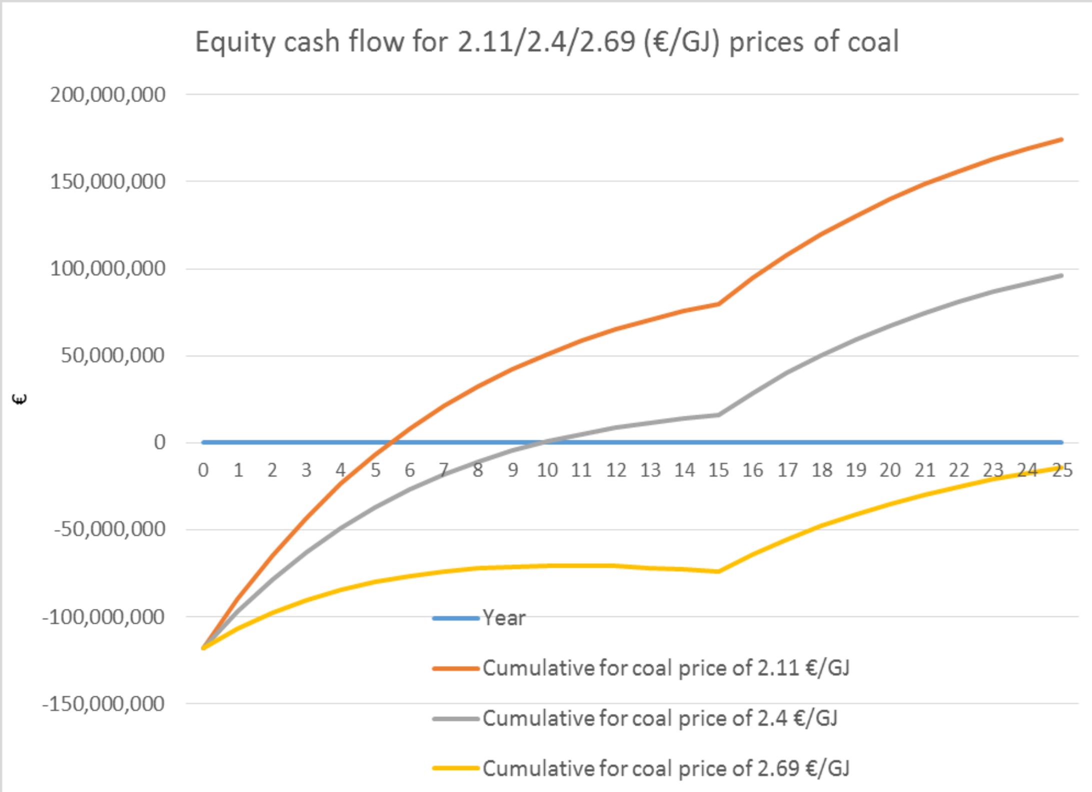

Figure 33. Impact of Coal Price on Equity Cash Flow of "Block 7 Tuzla".
This figure illustrates how the cumulative equity cash flow curves change when the price of coal drops for 12% or increases for 12% of the initial price of coal.

In the case of a higher price scenario, the calculation was made on the assumption that the price of coal in the first year of operation of "Block 7 Tuzla" is higher than the base scenario price (2.40 €/GJ) by 12%, which gives the price of 2.69 €/GJ. Figure 33 shows that the just 12% increase in coal price would make the project "Block 7 Tuzla" completely unprofitable. Even after the end of the lifetime which is 25 years, the invested capital would not be returned, so the investment would have to be rejected. The other case is for the 12% lower coal price than the base price scenario, which gives the coal price of 2.11 €/GJ. In this scenario, the equity payback time would be shortened from 10 to 6 years, while the cumulative equity cash flow would significantly increase. However, it is important to note that even the initial price of coal of 2.4 €/GJ from the base scenario is a fairly low price in BiH, when compared to the coal prices in the EU. This means that in reality the further 12% decrease in the coal price in BiH is far less likely to happen than the increase. Still, the scenario in which the price of coal further falls was considered to show the effects of the decline in coal prices on equity cash flow and the overall cost effectiveness of "Block 7 Tuzla". Table 56 displays the changes in the NPV, IRR, equity payback time and benefit-cost ratio as the results of the hypothetical changes in the coal prices in BiH.

Table 56

Sensitivity of the Profitability Indicators of "Block 7 Tuzla" to the Changes in the Price of Coal

Measure	Unit	By coal price of 2.11 €/GJ	By coal price of 2.4 €/GJ	By coal price of 2.69 €/GJ
NPV	(€)	174,353,838	96,219,029	-14,472,083
IRR	(%)	24.45	17.76	8.88
Equity payback time	(years)	6	10	>25
Benefit-cost ratio		2.48	1.82	0.88

Note. Data are personal calculations conducted in Fractal Software.

Table 56 clearly shows that the 12% increase in the coal price would make the project financially unfeasible, since all the profitability indicators are outside of the limits of cost-effectiveness. In other words, the project would generate a negative NPV value, the IRR of 8.88% which is smaller than the 10% discount rate, the equity payback time which is more than the actual lifetime of the power plant (during the lifetime, the positive return on investment would not be achieved) and the benefit-cost ratio which is smaller than 1, which means that the costs would be higher than the actual benefits of this project. It is obvious that the project would have to be dismissed, since it doesn't bring any benefit and ultimately generates losses. In the other scenario, the supply of coal at the 12% smaller price than the initial one, would give the excellent results of the investment project in terms of its profitability but as it has been said earlier it is not realistically possible in practice.

6.2 External Costs

Every electricity production is accompanied by the so-called external factors that can have a significant impact on the project's viability since they can increase the overall project costs during construction as well as during the project's lifecycle. Should these factors have a negative connotation, then we are speaking about the external costs. Such costs do not go as part of the internal costs and related profitability analysis, however should not be overlooked when making an investment decision in a power plant facility.

As stated by Borozan, Starcevic and Adzic (2015), the external costs of power plants are all the negative effects that the construction, operation and decommissioning of a power plant imposes on a third party (p. 2597). When it comes to electricity producing facilities, these external costs are mainly related to the negative impacts that such producers have on the local environment and the health of the local population in narrow sense and impacts on climate change and global warming from a broader point of view.

The reason why these negative external impacts are classified as costs is because the electricity producing facility almost always has to pay a compensation fee to a local municipality, state or some other government body or organization for the negative effects it caused. In these terms, one does not need to be an expert in order to clearly see the advantages of power plants based on renewable energy over the conventional coal-fired power plants. After all, these negative impacts are what stands behind the EU and other global incentives to encourage the production from renewable sources in order to fight the climate change and global warming.

When it comes to external costs related to the three analyzed power plants in BiH, from Chapter 5, the PV power plant and the wind farm have the clear advantage. As the matter of fact, the PV power plant “Kalesija” has no external costs at all. Located on the roof of a sports hall belonging to a local municipality it pays a symbolic fee for, this power plant causes no external effects on neither the environment nor the local population.

Regarding the WF “Mesihovina”, there are several external costs. According to Marincic (2015), the following fees are required to be paid to the local municipality of Tomislavgrad:

- annual fees paid for the concession and the right to use the site: 2.5% of the annual revenues;
- annual fees for the use of land for access roads: 10,931 €/year;
- annual fees for land use for laying the cable network: 856 €/year;
- one-time fee for change of environment and management of nature: 33.000 € (p. 132).

For example, when summed up, the total external costs for the first year of operation of the WF “Mesihovina”, including the one-time fee for the caused change of the environment and nature management, amount to 260,472 €, or 3% of the total annual income generated from the sale of electricity.

Naturally, the external costs are the greatest by the coal-fired power plants. According to Budgeting and Finance Service of the City of Tuzla (2017), the existing “Thermal Power Plant Tuzla”, as the power plant planned to be expanded with the analyzed “Block 7 Tuzla” production unit, pays the significant annual compensation fee of 2,700,000 €/year to the city of Tuzla for the consequences of environmental pollution (p. 3). For the most part, the city of Tuzla uses this fee for the sanitation of the consequences of coal mining on surface mines on the territory that belongs to city of Tuzla, planning and maintenance of land used for disposal of slag and ash from combustion chambers, procurement, installation and maintenance of the stations for monitoring gas and dust emissions from Thermal Power Plant Tuzla as well as for the final reclamation of slag and ash landfills that are no longer used for the slag and ash disposal.

Although the CO_2 emission trading system has not yet been established in BiH, its establishment is expected in the near future. So, when all the external costs that will follow the operation of “Block 7 Tuzla” during its lifetime, would be taken into account, then the total operating costs due to the high external costs would certainly contribute to further increase in the cost of investment and would result in even higher LCOE.

The EU itself, has devoted considerable attention to determining external costs and their inclusion in the total production cost of electricity. Also, external costs have become one of the factors in deciding the scope of production mix of electricity from renewable and conventional sources.

7. Final Considerations on the Electricity Production Mix in Bosnia and Herzegovina

The economic-financial analyzes carried out in the case study in Chapter 5 for the 3 power plants in BiH aimed at assessing the feasibility of each investment, based on the most commonly used methods such as the calculations of NPV, IRR, LCOE, equity payback time and benefit-cost ratio. The basic idea behind the whole analysis was to calculate individual indicators based on the same simplified formulas and forms for each project, and on the basis of the same assumptions of particular parameters (e.g. the same discount rate of 10% used in the analysis for all three power plants). In this way, the aim was to ensure that it is possible to compare the data at least for a number of common parameters.

Regardless of the fact that each of the considered power plants has a number of their own specific factors, from the aspect of making an investment decision, the calculated values with the above mentioned methods and conclusions based on these calculations represent a sufficiently strong basis for decision making on the eventual investment in a power plant construction.

The influence of the so-called external factors that inevitably accompany such investment projects were not included in the calculation of the profitability indicators, but rather discussed, identified and displayed for each power plant in the absolute amounts in chapter 6. It is worth noting that the participation of external costs in the total costs of a power plant can have a considerable impact on its financial viability.

Table 57 puts together all the calculated profitability indicators for each of the three power plants discussed in this thesis.

Table 57

Summary of the Calculated Profitability Indicators of the PV Power Plant "Kalesija", WF "Mesihovina" and "Block 7 Tuzla"

Power plant	LCOE	NPV	IRR	Equity payback time	Benefit-cost ratio
	(€ct / kWh)	(€)	(%)	(years)	
PV plant "Kalesija"	25.28	24,698	14.25	11	1.40
WF "Mesihovina"	7.32	18,753,693	29.00	5	2.87
"Block 7 Tuzla"	6.07	96,219,029	17.76	10	1.82

Note.

When concerning just the question if it would be financially profitable to invest in any of these three power plants, Table 57 clearly shows that, for the given parameters and assumptions based on which the calculations were made, all three investments can be considered economically viable because all three share the following common results:

a) NPV > 0;
b) IRR > *r* (discount rate of 10% for each project);
c) Equity payback time < Total lifetime of the power plant;
d) Benefit-cost ratio > 1 (benefits exceed the costs)

Concerning the LCOE, the calculated values are comparable to the values of similar projects in the EU, within the similar given time frames (year of construction and project lifetime).

If we analyze these results in detail, "Block 7 Tuzla" with a relatively low LCOE (6.07 € ct/kWh), high NPV (96,219,029 €), IRR of 17.76% which is greater than the discount rate of 10%, return on capital after 10 years and the very high capacity factor with 7000 operation hours per year could be a very attractive project from the aspect of cost-effectiveness. However, taking into account the most important volatility factors such as the variations (increase) in coal prices as propellant fuel, CO_2 emission trading and the costs of building facilities for CO_2 capture and storage, then the original image of the project's profitability could radically change and point to the need for further analysis that should give an answer to the project's realistic profitability when taking into account these costs as well. Furthermore, if we, in addition, consider the official EU policies and the policies of the other developed countries that seek to gradually reduce the use of coal in the production of energy until its complete elimination as a fuel source, as well as the increasing pressures of the local population and the non-governmental sector, we get another argument against the construction of a coal-fired power plant that could prove to be difficult to bypass.

The second power plant that could, on the basis of the calculations displayed in Table 57, seem to be worth investing in, would be the WF “Mesihovina”. The expansion of wind power plant construction in the EU and the world in general, based on a steady decline in the cost of equipment and the use of wind power as a free fuel, has shown that the time has come for wind energy to be commercially exploited, since it produces very little harms to the environment while simultaneously contributing to reductions in CO_2 emissions and other pollutants that are typical for the conventional power plants. This finding is also confirmed by the results of the profitability analysis of the WF “Mesihovina” displayed in Table 57. The case study proved that the WF “Mesihovina” as the first ever wind farm in BiH, is a profitable and financially feasible project, which could serve as an encouragement and a roadmap for the construction of further wind farms in BiH. The project is expected to achieve a quite solid NPV of 18,753,693 €, with the IRR of 29%, which is by far the most superior out of all three analyzed projects. The LCOE is a bit higher than the one of “Block 7 Tuzla”, however WF “Mesihovina” is superior to both other two projects in the investment return time and benefit-cost ratio. Although this project has a much lower NPV than “Block 7 Tuzla”, its benefit-cost ratio is much more favorable while the return on capital is double times shorter.

Regarding the PV power plant “Kalesija” project, it is obvious that the scale of the project is much smaller than those of the other two power plants. Accordingly, the calculated NPV of just 24,698 € is by far the lowest among the three analyzed investments, while all the other categories are falling behind as well. By far the highest LCOE is due to the very high volatility in electricity production, due to high dependence on the number of sunny days per year. Nevertheless, project certainly is profitable, but in a much smaller scale than the WF “Mesihovina” and “Block 7 Tuzla”.

Of course, based on the analysis of the indicators for only these three projects, it would be unwise to make an unambiguous and one-sided conclusion in terms of choosing one technology and ignoring the other. However, the conducted analyses and the first experiences collected during the realization of the two projects related to renewable sources, i.e. PV power plant “Kalesija” and WF “Mesihovina”, as well as the difficulties and delays in the construction of “Block 7 Tuzla” can be a good example of the practice that will help in the development of future similar projects.

However, on the basis of the results of the analyses in this paper, it is possible to derive suggestions on the optimal mix in the electricity production under the circumstances characteristic for the developing countries such as BiH.

Starting from current and future electricity needs in the function of securing the future sustainable economic growth and development of BiH, it is indispensable to consider a wide range of requirements, conditions and commitments undertaken at domestic, regional and international level in the fields of energy, environmental protection, energy efficiency and energy sector reforms.

BiH has defined the basic objectives and directions of future actions in the field of energy and the power sector in several key national documents. The most important document is the “Framework Energy Strategy of BiH by 2035”, by UK-BIH Reform Assistance to Bosnia and Herzegovina (2017). This document has been adopted by the Council of Ministers of Bosnia and Herzegovina, by unifying the framework energy strategies for the development of both entities, i.e. Federation of Bosnia and Herzegovina and Republic of Srpska, as well as that of Brčko District. The primary task of this framework was to define the direction of the energy sector development in BiH based on the policies of sustainable development that will ensure security of supply, price competitiveness and implementation of the de-carbonization policy, while aligning with the EU policies in these areas. With regards to electricity, this document was aimed at presenting the possibilities of developing a production mix of BiH, by analyzing some key parameters, but without giving a final proposal.

In analyzing the possible electricity production mix, UK-BIH Reform Assistance to Bosnia and Herzegovina (2017) stated that coal is still the dominant natural resource used for energy production in BiH and that, although the long-term energy sector development plan of BiH implies a reduction in the GHG emissions, this energy source will retain its dominant role in the near future (p. 8).

This framework strategy for the energy sector of BiH includes several scenarios out of which two are the most important when it comes to the future projections of the shares of conventional and renewable energy sources in the energy production mix. According to one scenario, by 2035, an increase of 108% in the total installed capacity is planned. In other words, in order to achieve this amount, a total of 4.9 – 6 billion € of new investments in energy sector is needed. What is most interesting in this scenario is that the planned share of coal in total produced electricity is planned to remain the same, with the cumulative coal consumption of 140 – 152 million tons (UK-BIH Reform Assistance to Bosnia and Herzegovina, 2017, pp. 66, 67 & 71). What this basically means is that, in order to fulfill this share, either the existing power plants at the end of their lifetime would have to be revitalized or completely new investments and construction of new thermal power plants of production units like “Block 7 Tuzla” would have to be undertaken. This further emphasizes that coal will still play a major role in the electricity production mix of BiH. The remaining shares would have to be fulfilled solely through the renewable energy.

The other scenario, named as the *renewable scenario with the energy efficiency* suggests the change of the electricity production mix portfolio in favor of renewable energy. According to this scenario, an increase of 38% in the total installed capacity in BiH by 2035 is planned, by which the share of total renewable energy sources would increase to 67% of the total installed capacity. In order to achieve this scenario, further investments of 2.1- 2.6 billion € in the energy sector would be needed. The share of coal should in this case decrease, or expressed in exact numbers, a decrease in cumulative coal consumption from 140-152 to 80-91 million tons (UK-BIH Reform Assistance to Bosnia and Herzegovina, 2017, pp. 77-71).

Obviously, the authors of the strategy have recognized that the importance of coal as fuel would still be high in both scenarios. Although the coal consumption of 140-152 million tons from the first scenario, falls in scope in the renewable scenario to 80-91 million tons, due to more intensive building of capacities based on renewable sources, and a certain reduction in the construction of coal-fired power plants, the level of consumption of this natural resource would still be relatively high.

Another factor of extreme importance especially for the developing countries is to secure the long-term electricity sales under favorable conditions. In order to achieve this, besides the obvious fact that the electricity should have to be sold at the prices higher than the costs of its production, a long-term and relatively stable production of electricity must be ensured as well. Because of the much higher volatility in the electricity production by the power plants based on renewable energy, and because of the high dependency of the developing countries like BiH on the electricity produced in coal-fired power plants, this is another factor that undermines the importance of coal in such countries, and that it will take a long time before they are completely put out of use. This of course brings out the question of the possibility of fulfilling the obligations of promotion and use of renewable sources set by the EU, in the function of reducing GHG emissions and reducing the impacts on the global warming of the planet.

BiH has significant reserves of coal and, in spite of the best intention of exploiting this natural potential, due to the series of internal weaknesses and the need for stronger investment in the restructuring of coal mines on the one hand, and EU policies and restrictions regarding the use of coal as fuel for environmental protection on the other, it is crucial to find an exit strategy, i.e. to seek the best production mix between coal and renewables, since it is obvious that no side can strictly dominate over the other in the energy sector of BiH in the upcoming years.

The authors of the above mentioned framework strategy for the energy sector of BiH emphasized the importance of increasing the electricity production in general, which necessarily requires the construction of new power plants. This means new investments for which developing countries such as Bosnia and Herzegovina do not have their own capacities due to the low accumulative capacities and questionable profitability of most of the existing production capacities, due to the numerous internal and systemic weaknesses. On the other side, the negative image in terms of attracting foreign investment capital will be much worse if we add to it the unstable political situation and the relatively high rate of indebtedness of BiH. Because of these reasons, the price of capital in commercial banks in BiH is twice as high as in the most EU countries. If we add to this, the policies of the large institutions such as the World Bank, the German Development Bank or other similar institutions, it is clear that the developing countries looking for fresh investment capital are turning to China as the largest investor in the projects related to construction of energy facilities or Japan where there are still limited possibilities for financing conventional power plant projects.

However, it can be argued that the mentioned framework strategy did not enough recognized the solutions of the EU in terms of transforming the energy sector from conventional to renewables dominated one. Energy efficiency, the organized and single electricity market, strong cross-border capacity, regional energy system linkage and the establishment of the regional electricity market are powerful elements of the EU policies that will contribute to the need for the construction of new power plants based on renewable energy.

The case study of the two first power plants based on renewable energy in BiH from Chapter 5, has shown that projects of this type can be easily profitable even in the developing countries such as BiH. The constant fall in the prices of the related equipment on the world market has enabled power plants based on renewables to become competitive to coal-fired power plants, even despite their known shortcomings with regards to the small factor of engagement of the installed power and significant dependence on wind and sun energy parameters. However, taking into account the impact of these key parameters, there are far fewer consequences for the final profitability of such power plants, than there are for coal-fired power plants if the price of coal would considerably rise, or, taking into account the costs of CO_2 emissions, established in the CO_2 trading system that is not yet active in BiH, but will certainly emerge in the near future.

However, a sharp reduction towards the total abandonment of electricity production from coal-fired power plants in BiH, before finding appropriate substitute economically viable solutions, would endanger the survival of coal mines and cause giant social problems, since a considerable number of people are employed in coal-fired power plants and coal mines. This would cause unforeseeable consequences for the development and growth of industrial production in the country and the GDP would take a massive hit.

Prior to the start of this research, the following three scenarios were assumed as the possible outcomes of the research:

a) rehabilitation of the existing coal-fired power plants by installing the technology to reduce emissions of GHG and SO_2 while at the same time increasing the investments in renewable energy plants that need to be substitute capacities for coal-fired power plants in order to gradually reduce the production from coal and to achieve the EU trends in these terms;
b) the construction of new coal-fired thermal power plants with fully applied technologies for reducing GHG and SO_2 emissions, with minimal investments in renewable energy plants (up to the fulfillment of the national quotas);
c) investment in new plants for electricity production based on renewable energy sources (sun and wind energy) without the rehabilitation or construction of new coal-fired thermal power plants.

Based on the results of the case study, it can be concluded without doubt that the scenario b), i.e. the construction of new coal-fired thermal power plants with fully-used technologies for reducing GHG emissions and SO_2 with minimal to no investments in renewable power plants, is not realistic due to several reasons. First of all, the systems for the capture and deposition of the CO_2 as the main cause of the greenhouse effect and the rise in global warming have not yet been sufficiently technologically developed. Second, the high price of installing the capacities for desulphurization increases the costs of the investment significantly, which puts developing countries such as BiH into even more difficult position to find the needed capital and investment funds for such investments. And finally, investing only in coal-fired power plants could seriously slow down or even completely stop BiH's path to the EU accession as the ultimate country's goal, since the required quota for the energy produced from renewable sources have not yet been fulfilled.

However, the other opposite as the scenario c) suggests, cannot be achieved either. It is obvious that the aforementioned mine closure problem, the complete shutdown of coal-fired power plants and all the resulting negative implications on the employment rate would have disastrous consequences for the country's economy. Furthermore, from a technical point of view, it is still impossible to produce energy only from renewable sources due to the high volatility in the production that highly depends on the availability of solar and wind power, while the technical as well as the financial solutions to store the energy from renewable sources do not yet exist.

The obvious conclusion would be that the scenario a), with the addition of the suggestions on the construction of only a certain (necessarily required) number of coal-fired power plants with the latest technology (BAT), could be a transitional solution that will meet both electricity and environmental requirements. This could prove to be the only possible scenario for BiH due to several reasons:

- for the production units of coal-fired thermal power plants in BiH, whose life span is not over yet, it is still possible to borrow the required funds on the financial market, for the purposes of reconstruction, extension of the lifespan and purchase of equipment to reduce harmful emissions in order to align it to the currently prescribed values of the EU;
- systematic investments in the production of electricity from renewable sources in the required scope will be able to compensate for the reduction of production from coal-fired thermal power plant blocks that will be out of operation due to the end of their lifetime;
- restructuring the coal mines would increase productivity and business competitiveness to a level that will ensure the long-term supply of domestic coal-fired power plants with the coal from national reserves at the economically acceptable prices and thereby prevent the negative impact of rising coal prices on the world market, with the final purpose to ensure the competitiveness of the prices of the produced electricity on the electricity market.

To conclude, the prospect of producing electricity from coal in the way it has been done in BiH so far has no prospect in the long run. The current level of emissions from the combustion plants is unsustainable both from the aspect of the EU policies and from the growing pressure of the local population, health- and non-governmental sector. BiH must take steps to fully meet the requirements of the EU acquis in the area of electricity production and energy sector through efforts to reach the set standards and undertaken commitments on the road to EU accession, but not at the cost of its own economic downturn. This will be a long-term struggle given that there are no capital resources in BiH for such large and radical investments, but with a good borrowing strategy, finding business partners willing to invest in concession models and approaching EU funds intended to adjust candidates for the EU membership, BiH can come close to the fulfillment of the EU requirements and conditions.

8. Conclusion

The subject of this research was the analysis of the profitability of investments in power plants based on renewable energy of sun and wind on one side, and the coal-fired power plant on the other, from the standpoint and under circumstances of Bosnia and Herzegovina, as an example of a typical developing country. The purpose was finding an optimal production mix between the two opposing electricity production technologies.

Until the end of the 20th century, conventional energy sources based on petroleum, natural gas, coal and nuclear fuels were untouchable in meeting energy needs and providing sustainable growth. However, over time, the consequences of the use of such sources (primary coal, oil and nuclear energy) on the environment and global warming have forced humanity to make a radical turn in securing energy needs by turning to the production of energy from renewable sources.

Developed western countries, especially the EU member states, have shown a high degree of responsiveness and leadership in changing the paradigm of using energy from fossil fuels in favor of renewable energy. At the same time, the EU has set requirements regarding the reform of the energy sector for all the other European countries that aspire to become full members of the EU. One of the focal points of these reforms is increasing the share of energy production from renewable sources.

Logically, a question emerged, whether at all, and if so, the developing countries such as Bosnia and Herzegovina are ready and capable to follow the set EU trends in the production and use of energy. Searching for an answer to this question was the motivation for this research, with the aim of contributing to the selection of the most optimal route or the so-called electricity production mix between conventional and renewable sources for the developing countries such as BiH and similar Western Balkan countries, because even in the best intentions, they will not be able to transform their energy sectors at the expected and required pace. The main obstacles to the rapid transformation towards low-carbon electricity production in such countries are the chronic lack of money for investment projects, high interest rates on loans, high costs of capital, unstable political situation and the inability to attract foreign capital to invest in otherwise attractive energy sectors.

Furthermore, there is an obvious conflict of interest. BiH and the Western Balkan countries, in the process of preparing for the EU accession and by joining the Energy Community, have committed themselves to transposing EU directives into local legislation and applying EU regulations and best practices in the energy sector. However, at the same time, they do not give up on the use of fossil fuels (primarily coal) because some of them, like in the case of BiH, even announce the construction of new coal-fired power plants, which directly questions the original institutional and state commitments to harmonize the state energy policies with the EU energy policy. This collision between the official acceptance of the EU energy policy and the announcement of own energy policies, which, in many segments, are not correspondent with the EU's policy, was an additional motive for finding the best production mix in BiH that could prove to be a winning strategy for the countries of similar status and aspirations.

In order to find these answers, the central point of the research was a case study and a profitability analysis of three power plants in BiH: “Kalesija” – the first photovoltaic power plant in the country, “Mesihovina” – the first wind farm in the country and “Block 7 Tuzla” – newly planned expansion of the existing coal-fired power plant. The subject of the analysis was the calculation of the key factors, costs and profitability indicators needed for assessing the profitability of each power plant and for making a decision on investing in their construction. The most important calculated measures, on the basis of which the direct comparisons between the three types of power plants was made, were: NPV, IRR, LCOE, equity payback time and benefit-cost ratio.

In addition, these calculated measures were then subject of a sensitivity analysis, in terms of how the profitability of these power plants reacts to the changes of, for all the three power plants common influencing factors, namely changes in the number of operating hours of a power plant, i.e. the installed capacity utilization factor and changes in the cost of capital expressed through a discount rate. In case of “Block 7 Tuzla”, the sensitivity analysis was expanded to the analysis of the changes in the prices of coal as well.

The calculated profitability indicators combined with the sensitivity analysis have pointed out the advantages and disadvantages of different technologies for electricity production and made the basis for making conclusions on the choice of optimal production mix.

The results showed that, out of all three power plants, the coal-fired “Block 7 Tuzla” yields by far the highest NPV, has the lowest LCOE and, naturally, has the highest capacity utilization factor, meaning that its construction would ensure the stable production of high amounts of electricity and would yield the highest benefits for both the investor and the country. However, despite the fact that the coal prices can be kept under control due to significant domestic coal reserves, after the eventual future application of the CO_2 emission trading system that is not yet active in BiH, the emission costs will significantly increase and the calculated measures will certainly suffer, while keeping in mind that the construction of the new coal-fired production units is contrary to the EU policies in any case.

However, the results of the analysis of the PV power plant “Kalesija” and WF “Mesihovina” clearly showed that the investments in such projects related to renewable energy in BiH can be easily profitable. Although both have certain problems related to the volatility in production due to high dependence on climate conditions, a continuous fall in the prices of components of these technologies and great solar and wind potentials in BiH will certainly make the investments in renewable energy in BiH more and more attractive and these two power plants could serve as a positive example.

The answer to the main question of the research was that BiH and similar countries, in the transitional period until the full implementation of the EU energy policies, can find a compromising mix between coal-fired power plants and power plants based on renewable energy. Since the complete shutdown of the coal-fired power plants would create an economic shock and increase the unemployment rate, the only reasonable strategy for such countries is to reconstruct the existing thermal power plants whose life span has not yet ended in order to meet the prescribed harmful emissions and to reduce the construction of new coal-fired power plants only to a necessary minimum, in order to ensure the long term electricity production and supply. At the same time these countries have to strongly boost the investments in the electricity production from renewable energy up to and above the envisaged national quotas in order to meet the EU policies. Power plants based on renewable sources will gradually have to replace the aging coal-fired power plants that are near the end of their lifetime and whose rehabilitation is not planned in order to transform the energy sector more and more in favor of renewables.

It is obvious that for BiH and similar developing countries, the changes in the energy sector are a necessity. Current policy of excessive dependence on coal-fired power plants is not sustainable in the long term, while energy production from renewable energy is no longer an addition to the energy sector, but is becoming the main drive. The developing countries will have to make the biggest efforts to fulfill the undertaken obligations from the EU, but not at the cost of their own economic fall. Although the renewables dominated energy sector is a long-term goal and a future, the conventional electricity production will continue to play a dominating roll for a considerable time in the future. The developing countries are not ready to make a radical shift in the energy sector and that is the reality. To what extent will this slow down the EU accession process, remains to be seen.

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